Essays in Open Economy Development

by

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ABSTRACT

This dissertation consists of two essays that deal with the development of open developing economies. These economies have experienced drastic divergence in terms of economic growth from the 1970s through the 2010s. One important feature of those countries that have lagged behind is their failure to build up their domestic innovation capacity.

The first chapter discusses the policies that may have an impact on the long-run innovation capacity of developing economies. The existing literature emphasizes that the backward linkage of foreign-owned firms is a key to determining whether foreign direct investment (FDI) is beneficial or detrimental to a domestic economy. However, little empirical evidence has shown which aspects of FDI policies lead to a strong backward linkage between foreign-owned and domestic firms. This paper focuses on the foreign ownership structure of these foreign-owned firms. It shows that joint ventures (i.e, firms with 1% -99% foreign share) have stronger backward linkages than MNC affiliates (i.e, firms with 100% foreign share) with domestic firms. I also find that the differences in backward linkages are strong enough to translate into a positive correlation between domestic innovation and the density of joint ventures and a negative correlation between domestic innovation and the density of MNC affiliates. Finally, I find that the channel through which foreign ownership structure affects domestic innovation raises innovation TFP in domestic firms. This results suggest that policies that affect the foreign ownership structure of foreign-owned firms could have a persistent effect on domestic innovation because they shift the comparative advantage of an developing economy towards the innovation sector in the long run.

The second chapter provides a unified theory to study what causes the divergence in economic growth of developing economies and how the innovation sector emerges in the developing countries. It shows that open developing economies become trapped at the middle-income level because they tend not to specialize in sectors that generate spillover or factor accumulation (the innovation sector). Using a dynamic Heckscher-Ohlin (H-O) model, this paper shows that the fast growth of developing economies tends to end before they can fully catch up with the developed world, and the innovation sector will not operate in the developing countries. However, the successful growth stories of Korea and Taiwan challenge this view. In order to explore the economic miracle that happened in Korea and Taiwan, this paper generalizes a dynamic Heckscher-Ohlin (H-O) model by introducing technology adoption and explore how it generates spillovers to domestic innovation. It shows that countries with policies that encourage technology adoption will benefit most from FDI: in addition to the fact that foreign technology raises productivity in the host country, the demand for skilled labor to adopt these technologies raises the education level in equilibrium, which benefits domestic innovation and leads to catch-up in the long run.

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1 THE LINK BETWEEN FOREIGN OWNERSHIP STRUCTURE AND DOMESTIC INNOVATION

1.1 Introduction

Since TFP growth was identified as the key factor that drives economic growth, research and development (R&D) activities have gained much attention from growth and development economists.[1] In the past 50 years, various countries have designed and implemented policies aimed at promoting domestic R&D activities.[2] Among these policies, those on foreign direct investment (FDI) have gained a lot of attention because they produce an essential impact on domestic innovation capacity.[3] However, the previous literature does not provide consistent results on whether foreign investment will encourage or discourage domestic innovation or what aspects of FDI policies may affect domestic innovation. In this paper, I provide empirical evidence to show FDI policy on foreign ownership structure in a developing economy has a persistent effect on its capacity for domestic innovation.

The paper addresses the following questions: Do policies regarding foreign ownership structure affect domestic innovation? If so, through which channel would these effects take place? And would these effects be persistent or just transitory? I document two major findings using Chinese firm-level data, as well as Chinese customs transaction-level data: First, foreign-owned firms have very different intermediate inputs sourcing strategies, trade patterns, and R&D intensities, depending on their foreign ownership structure. Second, at the industry level, the density of foreign-owned

[1] See Aghion and Howitt [1992], Aghion et al. [2002], Gorodnichenko et al. [2010]

[2] See Ergas [1987], Green et al. [1999]

[3] See Aitken and Harrison [1999], Gorodnichenko et al. [2010], Aghion et al. [2004]

firms with different foreign ownership structures does generate a strong impact on domestic innovation in their upstream industries, and this effect is persistent.

The previous literature studies the importance of vertical linkages between foreign-owned firms and local firms. Theoretical work, including Rodriguez-Clare [1996], claims that when foreign-owned firms are not closely linked with domestic suppliers, they would hurt the host economies in the long run. The upstream firms of these foreign-owned firms would suffer most because these highly efficient foreign-owned firms will crowd out their domestic counterparts, which are more closely linked with domestic suppliers. Empirical works, including Kokko [1994, 1996], Aitken and Harrison [1999], Kathuria [2000], Damijan et al. [2003], Kugler [2006] and Liu [2008], use firm-level data in multiple developing economies to examine the productivity spillovers from foreign-owned firms towards domestic firms along their supply chains. They find that the productivity spillovers from foreign-owned firms are undetermined. However, little empirical work provides direct evidence of the particular aspects of FDI policies that will cause this indeterminacy. The contribution of this paper is to bridge that gap by providing empirical evidence that the backward linkage of foreign-owned firms can be largely determined by their foreign ownership structure, which could be affected by FDI policies. In addition, I find that FDI policies that generate higher density of joint ventures in the markets will result in higher in domestic innovation in the long run.

This paper exploits two datasets—the "Chinese Annual Survey of Industrial Firms" (CASIF) and the "Chinese Customs Trade Statistics" (CCTS)—which are compiled and maintained by the National Bureau of Statistics and the General Administration of Customs of China, respectively. These datasets track detailed production, R&D and trade information for all large Chinese manufacturing firms. These datasets allow me to observe detailed sourcing and trade patterns, as well as R&D expenditures at the firm level. I will refer to foreign-owned firms with 100% foreign ownership as Multinational (MNC) Affiliates and foreign-owned firms with partial foreign ownership as Joint-ventures (JV). By comparing these firms in these datasets over the years, I am able to document the following new facts:

1. Backward linkages between foreign-owned firms and domestic firms are much stronger for joint ventures than for foreign-owned multinational affiliates.

a) Multinational affiliates source a much bigger portion of intermediate inputs from abroad than joint ventures do.

b) Multinational affiliates engage in a much bigger portion of processing trade, which has little connection with other domestic industries,than joint ventures do.

c) Multinational affiliates operate a much lower level of R&D activities than joint ventures do. Given that most innovative R&D in the multinationals has already taken place in their home countries, the R&D activities in the host economies are usually related to the localization of their products or technology transfers, which leads to higher backward linkages.

2. R&D expenditures are positively correlated with the density of joint ventures in downstream industries, but negatively correlated with the density of MNC affiliates in downstream industries. However, the production profits[4] exhibit the opposite pattern.

The data indicate that there are strong vertical linkages between joint ventures and domestic firms, but this linkage is much weaker between MNC affiliates and domestic firms. First, the imported portion of intermediate inputs is 130% higher in MNC affiliates than in joint ventures. Second, the portion of processing trade out of their total trade is about 300% higher in a multinational affiliate than in a joint-venture firm. Last, the R&D intensity is around 40% lower in the MNC affiliates than

[4]Computed using total sales revenue minus total input cost and managerial and operation costs

in the JV firms. From the above three points, I infer that, in general, compared with the MNC affiliates, joint ventures tend to source locally and to operate in a way that aims to gain access to the Chinese market, and they are forced (whether or not by Chinese FDI policies) to transfer some technology to their domestic partner. Thus, I claim that joint ventures have stronger backward linkages than MNC affiliates.

In order to study the link between foreign ownership structure and domestic R&D, MNC density and JV density in each manufacturing industry (which Rodríguez-Clare labels the linkage coefficient) are constructed using the Chinese input-output table (2007). The data suggest that vertical spillover towards domestic innovation productivity is positive from joint ventures but negative from MNC affiliates. I show the existence of innovation TFP spillovers in two steps: First, I show that a firm's R&D intensity (its R&D expenditures divided by its production profits) would increase by 10% if the density of joint-venture firms increased by 1% in its downstream industries; or it would decrease by 5% if the density of MNC affiliates increased by 1% in its downstream industries. However, in the next step, I show that production profits exhibit the opposite pattern, which is positively correlated with MNC density but negatively correlated with JV density. In the context of a standard model of how foreign ownership affects domestic firms' choice of R&D, I distinguish the "market-size effect" from the "spillover effect." The "market-size effect" and the "spillover effect" refer to an increase in the return on innovation and a decline in the cost of innovation, respectively, when the backward linkage from foreign firms is higher. The empirical findings suggest that joint-venture firms encourage domestic innovation not because of the "market-size effect," but because there is some pure "spillover effect": the only way to reconcile more innovation with lower profits is to see that it is easier to do the innovation (or higher innovation TFP). In the next chapter of my dissertation, I provide a general equilibrium model with international trade, which argues that the spillover effect is persistent because it changes the comparative advantage of a country.

My findings support the view that different levels of backward linkages between FDI and domestic firms would lead to very different responses in domestic R&D activities. Rodriguez-Clare (1996) studies how foreign-owned firms affect the host country through the generation of linkages. As an alternative explanation, he suggests that the linkage coefficient of multinationals is higher when communication costs between the headquarters and the production plant are high and when the home and host economies are not too different. His finding would suggest policies that aim to increase the "market-size effect," such as "infant industry protection" or "local content requirement," which have been intensively criticized in Krueger and Tuncer [1982], Harrison [1996], Tybout and Westbrook [1995], Kim [2000], Topalova [2004], and Muendler [2004]. As Rodriguez-Clare criticized in a later paper (Rodriguez-Clare [2007]): "To put it crudely, subsidizing the software sector may not generate a Silicon Valley in a developing country." In this paper, I propose new evidence about the "spillover effect": the ownership structure of foreign-owned firms affects the R&D spillover towards domestic innovators through backward linkages. My results suggest some implementable FDI policies that would favor foreign direct investment and encourage domestic innovation at the same time. These policies may pass both the Mill and Bastable tests,[5] which lead to the development of developing economies.

The remainder of the paper is organized as follows. Section 1.2 describes the Chinese manufacturing firm and trade data and how I combine these two datasets to get richer observations. Section 1.3 provides evidence on the foreign ownership structure

[5] Mill test requires that the protected sector can eventually survive international competition without protection, whereas the Bastable test requires that the discounted future benefits compensate the present costs of protection.

of individual firms and backward linkages. Section 1.4 provides a simple model that shows how to distinguish the spillover effect through backward linkages from the demand effect through backward linkages. Section 1.5 presents an empirical analysis of how the foreign ownership structure of foreign firms affects domestic innovation, using the above datasets, and discusses the results of the estimations. Section 1.6 concludes.

1.2 Data

I study two main sources of information from Chinese firm-level and transaction-level datasets. The firm-level dataset is from the "Chinese Annual Survey of Industrial Firms" (CASIF) collected by the National Bureau of Statistics in China. The transaction-level data come from the database of the Chinese Customs Trade Statistics (CCTS), which is compiled and maintained by the General Administration of Customs of China.

Manufacturing firm data

The CASIF survey data comprise a firm-level dataset, which surveys the greatest number of Chinese firms and records the most firm variables between 2000 and 2009. On average, more than 250,000 firms are surveyed each year, accounting for around 95% of total Chinese industrial output and 98% of industrial exports. Two groups of firms are included in this survey. The first is all state-owned firms, and the second is firms with annual sales above USD 800,000. According to Cai and Liu [2009], firms are given assurance that information from this survey will not be released or used against them by other government agencies, such as tax authorities. For these reasons, firms have less incentive to misreport the information.

The data contain detailed information on their production activities, accounting statements, and basic characteristics such as foreign ownership structure, location and industry.

The sample I use from this dataset is from 2004 to 2007. An important feature of this sample is that it has information on firms' research and development (R&D) expenditures between 2005 and 2007, which is the main focus of this paper. Other important information, including the foreign share and intermediate good use of a firm, is available throughout the sample years.

Following Upward et al. [2010], I drop firms classified as being in the mining, energy, tobacco, and handicrafts industries. I also clean the data by deleting observations that are considered to be incorrect or are outliers. [6].

Table 1.1 provides a brief description of the cleaned CASIF sample.

Trade data:

The trade data record all transactions passing through Chinese customs monthly from 2000 to 2006. The census includes firms' basic information (name, address, foreign ownership, etc.), which I use to identify individual firms; and product codes (in HS-8), which I use to identify the commodity type.

In addition, transactions are classified under one of 18 "customs regimes" (see Table A.1 in Appendix) to help us understand what is behind each transaction. For example, if an imported good enters China as an intermediate good and will be processed and sold outside of the Chinese market, then it will be logged as one of the "processing trade" category (with customs regimes labeled as "Processing and

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The observations will be cleaned if the following conditions are satisfied: (1) missing or non-positive values on any of the variables related to output, sales, capital, and intermediate inputs; (2) number of employees is missing or fewer than eight employees; (3) missing or negative values on any of the variables related to foreign ownership structure and export value; and (4) value of sales is less than export value.

Assembling" or "Processing with imported materials"). These transactions will be one of the main focuses of this paper. The Broad Economic Categories (BEC) code is also utilized to categorize the imported goods in each transaction. It helps in identifying intermediate goods in each transaction, which sum up to the intermediate good imports at the firm level. This will be one of the main focuses of this section, as well.

Since the firm data cover only the manufacturing sector, I drop the service trade from the original CCTS data. Table 1.1 summarizes the remaining manufacturing trade data from the CCTS.

Finally, these datasets will be used jointly in the empirical section.[7] The information contained in different datasets is matched by the firm's name, telephone number and zip code. And the matched results are also summarized in Table 1.1.

Table 1.1: Data Summary

	CASIF Data	CCTS Data		Matched Data	
Year	#Firms	#Transactions	#Firms	#Firms	Matched Ratio (%)
2004	202,007	19,697,828	153,603	63,966	31.7%
2005	204,965	22,812,443	179,317	65,879	32.1%
2006	232,842	25,658,033	208,017	71,108	30.5 %
2007	271,705	–	–	–	–

foreign-owned firms in the Chinese manufacturing sector

Between 2004 and 2007, on average, 10.1% of firms that operated in China were considered foreign-owned. They accounted for 14.1% of total employment, 18.2% of total value added and 21.3% of total sales. On average, they had higher sales and created more value added per worker, which indicates that they had higher

7 In Appendix

productivity than the average domestic firm. As Table 1.2 shows, these foreign-owned firms were concentrated mainly in the "Machinery and Computer Equipment" and "Apparel" industries. Between 2004 and 2007, on average, 20.7% of foreign affiliates were in the "Machinery And Computer" industries, where they hired more than 28% of the total employees and accounted for around 37.3% of the total sales of all the foreign-owned firms. The "Apparel" industry hosted the second-most foreign-owned firms in terms of both the number of affiliates and total employment, but it only accounted for less than 4% of total sale and value added. Although other sectors do not hire as many employees, foreign-owned firms in China invest in almost every kind of industry and play an important role there.

Table 1.2: Foreign-owned firms In China

Industry name	Firm share	Employment Share	Value added Share	Sales Share
Food And Kindred Products	7.20%	6.03%	6.51%	5.73%
Textile Mill Products	7.39%	5.72%	2.63%	2.45%
Apparel And Other Finished Products Made From Fabrics And Similar Materials	11.99%	13.60%	4.43%	3.63%
Lumber And Wood Products, Except Furniture	1.45%	0.80%	0.47%	0.39%
Furniture And Fixtures	1.72%	1.87%	0.79%	0.76%
Paper And Allied Products	1.71%	1.40%	1.66%	1.51%
Printing, Publishing, And Allied Industries	3.13%	2.80%	1.05%	0.91%
Petroleum Refining And Related Industries	0.32%	0.33%	1.38%	2.24%
Chemicals And Allied Products	8.03%	4.68%	9.06%	7.58%
Rubber And Miscellaneous Plastics Products	6.13%	5.15%	3.36%	3.09%
Stone, Clay, Glass, And Concrete Products	4.12%	2.76%	2.10%	1.59%
Primary Metal Industries	0.91%	1.23%	3.63%	4.05%
Fabricated Metal Products, Except Machinery And Transportation Equipment	6.09%	4.27%	4.23%	4.32%
Industrial And Commercial Machinery And Computer Equipment	20.70%	27.99%	31.92%	37.32%
Transportation Equipment	5.01%	6.27%	11.60%	11.46%
Electronic And Other Electrical Equipment And Components, Except Computer Equipment	6.72%	7.94%	6.79%	6.66%
Measuring, Analyzing, And Controlling Instrument	2.42%	2.60%	2.41%	2.40%
Other	3.96%	3.16%	2.94%	2.22%

Data Source: CASIF (2004-2007)

Two kinds of foreign-owned firms: MNC affiliates vs. Joint-venture firms

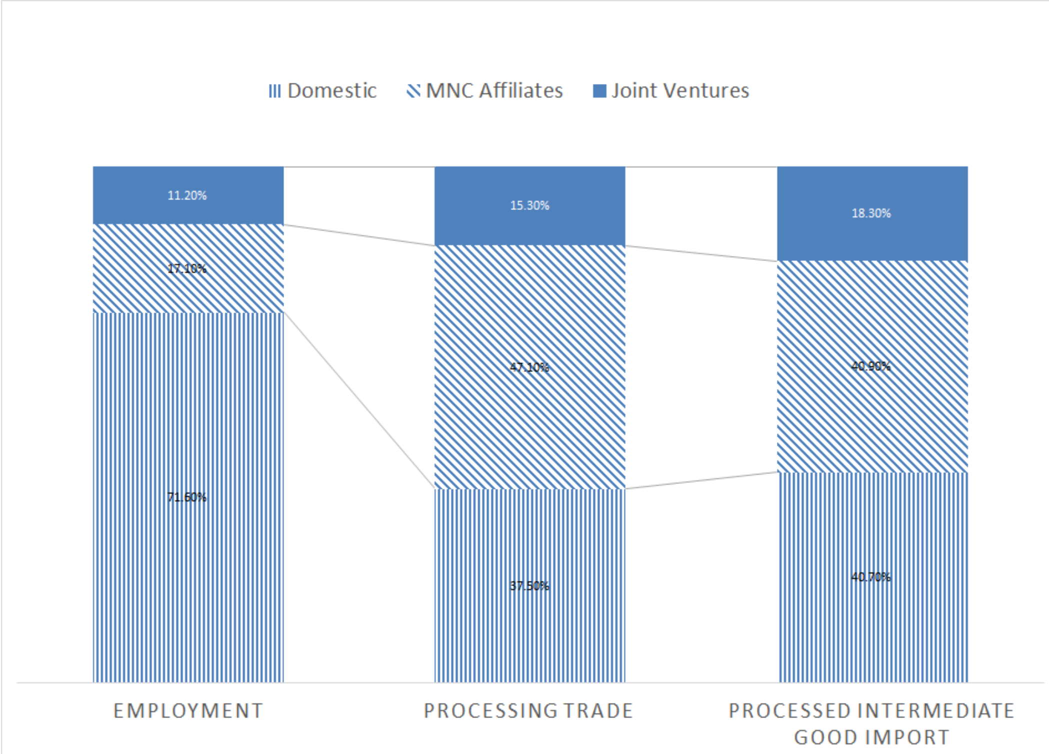
An important distinction of this paper is that I distinguish between foreign firms that are 100% foreign-owned from firms and with less than 100% foreign-owned. In the dataset, I have the value of assets, in dollars, owned by each party (i.e. state, private and foreigners). Using firm assets owned by foreigners divided by total firm assets, I calculate the index for the foreign share of each FDI firm.

$$\text{Foreign Share} = \frac{\text{Foreign Assets}}{\text{Total Assets}} \tag{1.1}$$

These foreign-owned firms are classified into two categories based on their foreign ownership structure. I define a firm as an MNC affiliate if and only if Foreign Share = 100%; I consider all other foreign-owned firms joint-venture firms.

As Figure 1.1 shows, in firms that have positive trade records, MNC affiliates and joint-ventures account for 17% and 11% of total employment, respectively. Despite their relatively small employment, these two types of foreign-owned firms are active players in Chinese trade, but with some distinctions. The first involves their sourcing strategy: between 2004 and 2006, these MNC affiliates sourced more than 40 percent of Chinese total intermediate inputs alone, while this number was much lower in the joint ventures. Another distinction is that MNC affiliates are especially active in trade that is classified as processing trade: 60% of total trade in these MNC affiliates is classified as processing trade. Between 2004 and 2006, the MNC affiliates accounted for half of all Chinese processing trade, while the joint ventures accounted for only about 15%.

Figure 1.1: Distinction Between MNC Affiliates And Joint-ventures



Data Source: CASIF (2004-2007), CCTS (2004-2006)

A third distinction between MNC affiliates and joint ventures is related to technology transfer. Holmes et al. [2013] document the fact that the Chinese government is using "Quid Pro Quo" FDI policies. They claim that every foreign firm, if it wants to get access to the Chinese market, is required to transfer some of its technologies to domestic firms. From Figure 1.1, we infer that MNC affiliates, which engage mainly in processing trade and are not targeting Chinese markets, are affected less by such a policy; however, joint-venture firms, which target Chinese markets, will be affected by such FDI policies and must transfer their technologies. In 2006, MNC affiliates devoted 1.7% of their profit or 1.1% of their value added to research and development activities, while these numbers were 3.5% and 2.2%, respectively, for joint-venture firms—more than twice as much as the MNC affiliates. As McGrattan and Prescott

[2009] claim, joint-venture firms may invest more in R&D activities in order to enable them to absorb the technologies from their foreign partners.

In what follows, I analyze these three distinctions between MNC and joint-venture firms in more detail. In particular, I establish the fact that joint-venture firms are more closely related than MNC affiliates with the domestic economy or, in other words, potentially have stronger backward linkages with domestic firms.

1.3 Potential backward linkages

This section compares the above three distinctive trade and R&D patterns in MNC affiliates and joint-venture firms to establish the stylized facts. I observe processing trade, domestic intermediate-goods sourcing, as well as domestic R&D activities in these foreign-owned firms to determine if foreign ownership structure plays a role in determining their backward linkages to domestic firms. I show that joint-venture firms have tighter backward linkages with domestic firms than do MNC affiliates.

First, backward linkages must be defined. Similar to Rodriguez-Clare [1996],[8] I assume that a foreign final-goods firm that prefers to use domestic intermediate inputs has higher backward linkages. I use the letter μ to index the backward linkages, with higher μ representing tighter backward linkages.

Based on this definition, three proxies are made to capture the backward linkages μ in these foreign-owned firms.

The first proxy, the percentage of processing trade ($S_{Processing}$), is constructed using the sum of processing imports and exports divided by the sum of total imports

[8] Rodriguez-Clare [1996] defines “backward linkages” and emphasizes their importance: Although it is well known that foreign-owned firms will achieve great productivity gains in the final sector, if these foreign-owned firms in a developing economy do not have strong backward linkages, they may reduce both the variety and the productivity of their upstream firms. Such a disparity would cause a developing economy to specialize in the final sector, which is usually unskilled-labor-intensive and generates few spillovers to other industries.

and total exports of that firm. According to the Chinese customs regime classification, processing trade is defined as importing parts and other intermediate materials from abroad and then, after processing or assembly, exporting the finished products. According to this definition, a higher processing trade share suggests that a firm is less likely to choose domestic intermediate inputs or to use domestic services to distribute their outputs. Thus, firms with high $S_{Processing}$ are less likely to generate enough demand to help their domestic partners thrive. Therefore, according to the previous arguments, a high level of this ratio will imply lower backward linkages.

The second proxy, the percentage of intermediate imports ($S_{Import\,Intermediate}$), is also constructed at the firm level, using imported intermediate goods (excluding raw materials and fuels) divided by total intermediate goods used (excluding raw materials and fuels). According to the previous discussion, a high imported share of intermediate inputs may reduce the demand for domestic firms, thus implying lower backward linkages.

Besides the above two direct proxies, the intensity of R&D activities ($S_{R\&D}$), which is constructed using R&D expenditures divided by the total profit of an FDI firm, is also used to proxy potential backward linkages. This is because, for foreign-owned firms, most innovative R&D has already taken place in their home countries, while R&D activities in the host economies are usually related to the localization of their products or their targeting of technology transfers.[9] Thus, an FDI firm with more aggressive R&D choices tends to either source more or sell more in the domestic market. Thus, when a foreign firm's $S_{R\&D}$ increases, that raises its backward linkage level.

[9] Kinoshita [2000], Bin [2008]

Using these three proxies, I compare the backward linkages that are generated by MNC affiliates and joint-venture firms, respectively. The result is shown in the remainder of this section.

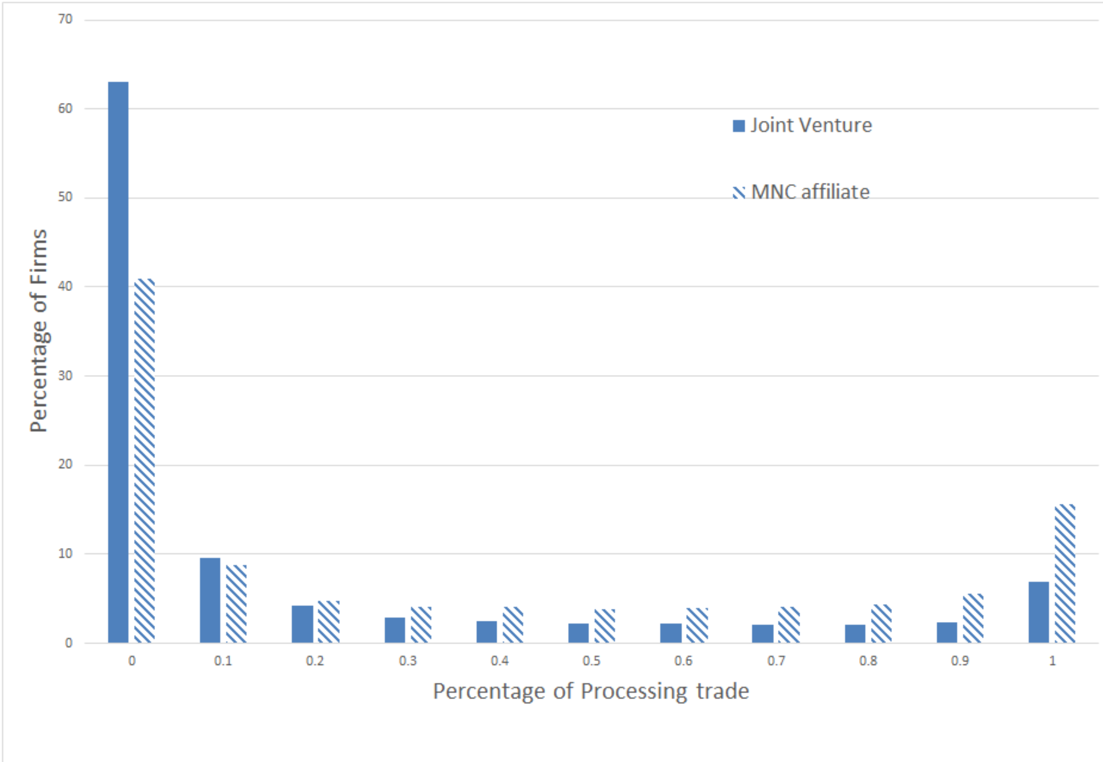
A glance at the relationship between foreign ownership structure and potential backward linkages.

In this section, the firm samples that I consider are different when I focus on different proxies. For the first two proxies, I focus on foreign-owned firms that have information recorded in both the CASIF and CCTS datasets between 2004 and 2006. For the last proxy, I focus on all foreign-owned firms that were included in the CASIF between 2005 and 2007. The years and the datasets are selected to maximize the number of observations for each proxy.

Share of processing trade

I first look at the share of processing trade. From Figure 1.2, I observe that MNC affiliates are significantly more active in the processing trade. Almost one fifth of MNC affiliates do all of their trade through processing trade, which suggests that these firms contribute nothing to firms in domestic industries. Compared with these MNC affiliates, the joint-venture firms are significantly less active in processing trade: two thirds of joint-venture firms do no processing trade, while this number for MNC affiliates is 40%.

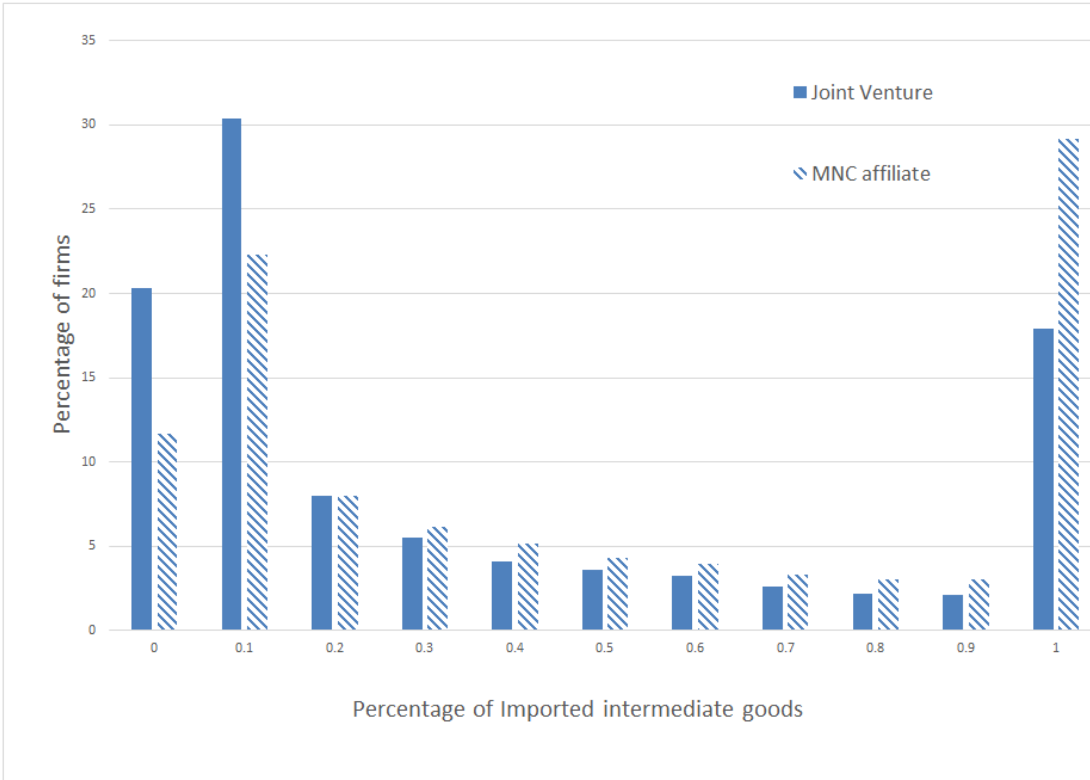
Figure 1.2: Share Of Processing Trade $S_{Processing}$



Share of imported intermediate goods

The second observation concerns the share of imported intermediate inputs. From Figure 1.3, I observe that MNC affiliates import a higher fraction of their intermediate inputs than joint ventures do. One third of MNC firms import all their intermediate goods from abroad. On the other hand, more than half of joint ventures use less than 10% of imported intermediate inputs, while this number is about one third for MNC affiliates.

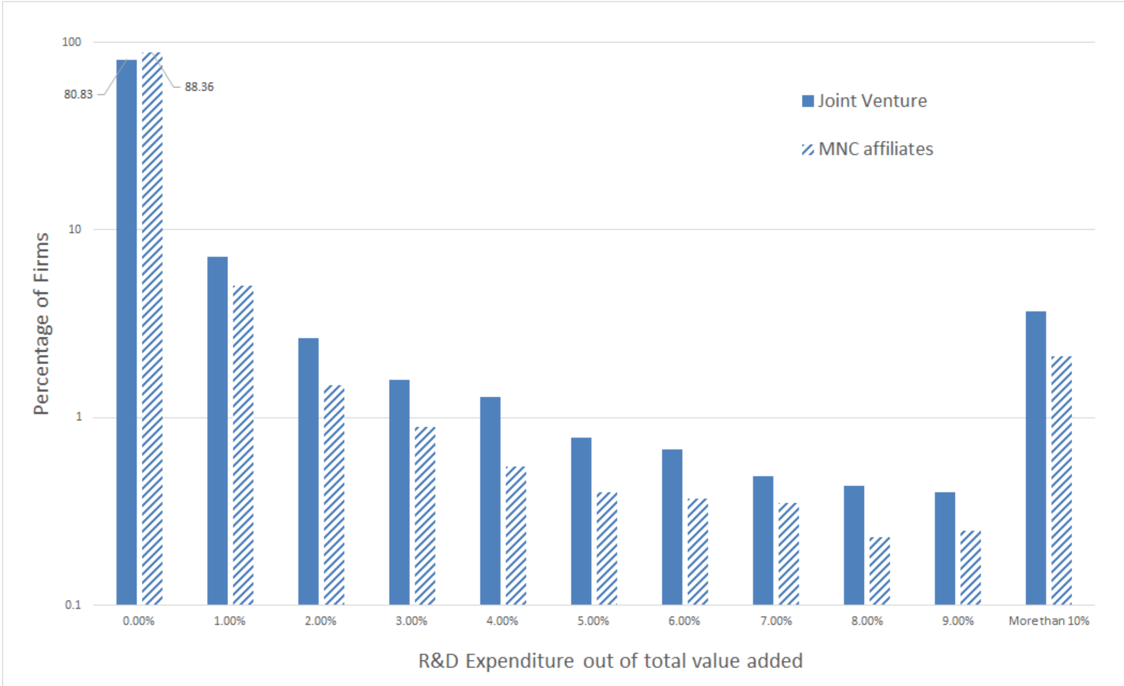
Figure 1.3: Share Of Imported Intermediate Imports $S_{Import\,Intermediate}$



R&D investment intensity

Figure 1.4 displays the density of R&D intensity of both types of foreign-owned firms. I observe that only 10 % of MNC affiliates invest in R&D, while this number is twice as much for JV firms. And I observe that the density function of JV firms has a significantly fatter tail than that of the MNC affiliates.

Figure 1.4: R&D Intensity $S_{R\&D}$



Regression results

I then regress these new proxies on foreign ownership structure to see how the foreign ownership structure in foreign firms affects backward linkages. I introduce dummy variable "MNC" and let it equal "1" if and only if it is an MNC affiliate. Since I consider only firms within the category of foreign-owned firms, $MNC = 0$ when this firm is a joint-venture firm. I control for area fixed-effects (η_a),[10] industry fixed-effects (η_j) and time fixed-effects (η_t) using dummy variables. I estimate the following equations for backward linkage proxies $Y = \{S_{Processing}, S_{Import\,Intermediate}, S_{R\&D}\}$ in each firm i:

$$(Y)_{ijat} = \beta_0 + \beta_1 MNC_{it} + \beta_2 * \eta_a + \beta_3 * \eta_j + \beta_4 * \eta_t + \varepsilon_{ijat}$$

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In terms of the performance of China's economy, four regions—Northeastern China, Eastern China (Coastal area), Middle China and Western China—are distinguished from each other; one additional dimension of the area dummy is whether or not the firm is located in a large city (a city with a five million or greater population)

The data sample for the first two regressions includes only matched foreign-owned firms in both the CASIF and CCTS datasets between 2004 and 2006.[11] This is because the information about trade details are included only in the CCTS datasets, while details about firms' accounting are available only in the CASIF datasets. In addition, as I show in the Appendix, the match sample is unbiased from the entire sample in the CASIF datasets. The third regression includes all firms in the CASIF datasets between 2005 and 2007 because the R&D investment information at the firm level is available only for these years.

Using panel regressions, in the first columns of Tables 1.4, 1.5 and 1.6, respectively, I find that the $S_{Processing}$ in the MNC affiliate is three times as much as that in JV firms; $S_{Import\,Intermediate}$ is around 100% higher in the MNC affiliate than in the JV firms; and $S_{R\&D}$ is around 40% lower in the MNC affiliates than in the JV firms. In the second columns of these tables, I control for the three-digits industry dummy, are a dummy and time dummy and get similar results. As interpreted in the previous section, the basic results suggest that joint ventures have a higher backward linkage effect than MNC affiliates.

In the next step, I control some firm features, as well as industry and geographical features, to estimate the following equation under both methods:

$$Y = \beta_0 + \beta_1 MNC + \beta_2 S_{Export} + \beta_3 \ln(\frac{K}{Y}) + \beta_4 \ln(H)$$

11 The data-matching process follows Tian and Yu's [2012]. Details of the data matching are included in the Appendix.

$$+\beta_5 S_{long-term} + \beta_6 * \eta_a + \beta_7 * \eta_j + \beta_8 * \eta_t + \varepsilon_{ijat} \tag{1.2}$$

In these equations, the dummy variable MNC is my main focus. Other useful factors include Capital intensity $\ln(\frac{K}{Y})$; average Human capital stock $\ln(H)$, [12] size of firm measured by its value added $\ln(VA)$; the share of the firm's exports out of its output S_{export}; the share of long-term investment out of its total assets $S_{Long-term}$; and dummies for the industry (η_j), area (η_a) and time (η_t)of individual firms. The expressions of these variables are summarized in Table 1.3.

Table 1.3: Variable Expressions In Regressions

Variable Name	Variable Expression
$S_{Processing}$	$\ln(s_{Processing} + e^{-10})$
$S_{Import\,Intermediate}$	$\ln(s_{Import\,Intermediate} + e^{-10})$
$S_{Long-term}$	$\ln(\frac{\text{Long term Investment}}{\text{Total Asset}} + e^{-10})$
S_{export}	$\ln(\frac{\text{Export Value}}{\text{Sales Value}} + e^{-10})$
Industry Dummy (η_j)	3-Digit GB code
	Eastern (coastal), North Eastern
Area Dummy (η_a)	Middle, West
	Belong to 5 million+ population city

I do regressions for $Y = \{S_{Processing}, S_{Import\,Intermediate}, S_{R\&D}\}$ and on MNC and the above firm control variables. Tables 1.4, 1.5 and 1.6 summarize the results. Column 3 in all tables is the regression results for these panel regressions; since around 30%, 20% and 90% of the firms do not engage in processing trade, import

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Bils and Klenow [2000]: $H = e^{\phi(s)}$

intermediate goods and perform R&D activities at all, I do a Tobit regression and summarize the results in the last column of each tables, respectively.

Table 1.4: Impacts Of Foreign Ownership On $S_{Processing}$

Dependent Variable: $S_{Processing}$	Panel	Panel	Panel	TOBIT
VARIABLES	(1)	(2)	(3)	(4)
MNC Dummy	**1.202*****	**1.087*****	**1.114*****	**3.275*****
Capital intensity			-0.236***	-0.695**
Human Capital intensity			-3.194***	-3.754***
Long term investment			-0.023***	-0.105***
Export Share			2.104***	9.129***
Value added			-0.276***	-0.782***
Area Dummy	No	Yes	Yes	Yes
Time Dummy	No	Yes	Yes	Yes
Industry Dummy	No	Yes	Yes	Yes
Observations	94899	94899	83084	83084
left-censored	–	–	–	39071

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 1.5: Impacts Of Foreign Ownership On $S_{Import\,Intermediate}$

Dependent Variable: $S_{Import\,Intermediate}$	Panel	Panel	Panel	TOBIT
VARIABLES	(1)	(2)	(3)	(4)
MNC Dummy	**0.688*****	**0.721*****	**0.674*****	**1.243*****
Capital intensity			0.142***	-0.302***
Human Capital intensity			0.969***	1.349***
Long term investment			-0.027***	-0.060***
Export Share			1.342***	2.369***
Value added			-0.145***	-0.230***
Area Dummy	No	Yes	Yes	Yes
Time Dummy	No	Yes	Yes	Yes
Industry Dummy	No	Yes	Yes	Yes
Observations	94899	94899	83084	83084
left-censored	–	–	–	13365

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 1.6: Impacts Of Foreign Ownership On $S_{R\&D}$

Dependent Variable: $S_{R\&D}$	Panel	Panel	Panel	TOBIT
VARIABLES	(1)	(2)	(3)	(4)
MNC Dummy	**-0.400*****	**-0.424*****	**-0.417*****	**-3.164*****
Capital intensity			0.143***	0.732***
Human Capital intensity			1.617***	8.987***
Long term investment			0.039***	0.393***
Export Share			0.009***	0.066***
Value added			0.223***	1.753***
Area Dummy	No	Yes	Yes	Yes
Time Dummy	No	Yes	Yes	Yes
Industry Dummy	No	Yes	Yes	Yes
Observations	130696	130696	115204	115204
left-censored	–	–	–	99930

*** p<0.01, ** p<0.05, * p<0.1

The main take-away from the above three regressions of equation (1.2) is that compared with JV firms, MNC affiliates engage in significantly more processing trade, use a significantly higher share of imported intermediate goods and engage in significantly less R&D. This effect remains significant when I control for many aspects of firms, which implies that joint ventures have stronger backward linkages with domestic firms than MNC affiliates do. The results in Tables 1.4, 1.5 and 1.6 contain two important findings. First, the coefficients on the MNC dummy are statistically significant, which implies that there are meaningful backward linkages between the two types of foreign-owned firms. Second, the estimated coefficients for MNC affiliates are all much different from 0, implying that JV firms (MNC=0), when compared to MNC affiliates, are the main contributors to the FDI backward linkages in a country. This finding is important because it implies a basic assumption: industries with a higher density of JV firms will have higher industry-level backward linkages towards their upstream industries than industries with a lower JV density.

To summarize, in this section, I discussed three proxies for the backward linkages of foreign-owned firms. Overall, the data consistently show that joint ventures have significantly stronger backward linkages with the host economy than MNC affiliates do. Using this information, I will study how FDI policies regarding foreign ownership structure might affect domestic innovation in the host country and discuss whether these policies would succeed in a Mill test: the policy-affected sector can eventually survive international competition without any further protection.To see this, one must consider whether or not the policy will help the policy-affected sector gain comparative advantage in the long run. Thus, I provide a simple model of a domestic innovator's decision to choose the optimal innovation intensity. I use this model to identify a channel through which FDI policies affect the comparative advantage of domestic innovation.

1.4 Model

The previous section documented that different backward linkages exist between foreign firms with different foreign ownership structures. In this section, I return to the paper's main question: How might these differences affect the domestic innovation sector?

There are two hypothetical channels through which foreign backward linkage may affect domestic innovation. One hypothesis is that backward linkage creates spillover towards innovation, which reduces the cost of research and development in domestic firms. I call this channel the "spillover effect." Intuitively, this "spillover effect" is positive when a local-sourcing foreign-owned firms provides direct or indirect help to its partners, enabling them to become part of their supply chain and, thus, to serve as substitutes for the firm's foreign suppliers. A natural alternative hypothesis is that backward linkage would enable upstream firms to earn more profit from each single innovation. This channel I call the "market-size effect." Intuitively, the "market-size effect" is positive when higher foreign backward linkages increase the fraction of domestically supplied inputs and raise domestic firms' profits.

These two channels lead to very different policy implications. If a policy includes the "spillover effect," it would have a persistent effect on domestic innovation: a TFP increase in the innovation sector would help the developing economy build up comparative advantage in innovation and move the economy to a "high-skill and high-innovation" equilibrium. Even if these FDI policies are canceled or changed in the future, this comparative advantage will still last. However, if only the "market-size effect" exists in a policy, then this policy is nothing more than "trade protection," and its effect on domestic innovation will be transitory. When the protection ends, foreign-owned firms will resume their original sourcing strategy, and domestic firms will no longer have a strong incentive to innovate.

Innovation model

In this section, I introduce a simple partial equilibrium model that describes domestic firms' choice of innovation intensity, which is similar to Aghion et al. [2004] "competition escape model." This model incorporates both the "spillover effect" and "market-size effect" and is able to distinguish between these two effects under certain circumstances.

Suppose that the potential backward linkage index from the FDI firm is μ , which measures the extent to which foreign-owned firms prefer domestic goods to imported goods. A higher μ would suggest that foreign-owned firms would like to source a larger fraction of their intermediate inputs from one or more domestic firms if goods from domestic firms meet their standards. Such a sourcing strategy would result in a profit of $(\mu)^{\beta_0}\pi$ for their upstream domestic firms. β_0 in this expression is an index for the "market-size effect." When β_0 is positive, a higher foreign backward linkage would result in higher expected profits in domestic firms.

A domestic firm needs to innovate in order to keep up with the world frontiers (i.e., be qualified to sell its products to any globally-sourcing final plants). Suppose that the innovation intensity is indexed by γ . With probability γ , this firm becomes part of the global supply chain of an FDI firm and will expect a profit of $(\mu)^{\beta_0}\pi$; with probability $1-\gamma$, the innovator fails in the innovation and would not be a qualified supplier; however, a certain amount of profit $\lambda(\mu)^{\beta_0}\pi$, where $\lambda \in (0,1)$, would still be achieved due to protection policies such as the "minimum local content act" and the "infant industry protection act." $\lambda = 0$ if such trade protection acts do not exist.

$$\text{Local Firm Profit} = \begin{cases} (\mu)^{\beta_0}\pi & \text{with probability } \gamma \\ \lambda(\mu)^{\beta_0}\pi & \text{with probability } 1-\gamma \end{cases}$$

The cost of domestic innovation is related to the innovation intensity γ, as well as to the backward linkage μ. In particular, a domestic firm that faces backward linkage μ and decides to innovate at intensity γ will use $\mu^{\beta_1}H(\gamma)$ units of resources. β_1 in this expression is an index for the "spillover effect." When β_1 is negative, a higher foreign backward linkage will reduce the innovation cost or raise the innovation TFP in domestic firms.

I assume that domestic innovators who take the backward linkage index μ and the total market size π as given are competitive in the market, and they choose the optimal innovation intensity γ that maximizes their expected profit from the innovation.

$$\max_{\gamma} \gamma\mu^{\beta_0}\pi + (1-\gamma) * \lambda(\mu)^{\beta_0}\pi - \mu^{\beta_1}H(\gamma) \tag{1.3}$$

Let $H(\gamma)$ be a convex and increasing function in the innovation intensity γ. For simplicity, I assume that it takes the form $\frac{c\gamma^2}{2}$, in which c is properly chosen to guarantee that the optimal innovation intensity γ is between the interval [0,1] (γ is specified in (1.4)) . Take the first-order conditions of the innovator's problem (1.3) , which gives:

$$\gamma = \frac{(1-\lambda)(\mu)^{\beta_0}\pi}{c\mu^{\beta_1}} \tag{1.4}$$

From the innovation index γ , I can define the innovation intensity (I) of a firm as the ratio of R&D expenditures ($\mu^{\beta_1}H(\gamma)$) to expected firm profit ($[\gamma(1-\lambda)+\lambda]\mu^{\beta_0}\pi$), which represents how aggressive this firm is in acquiring new technologies. Domestic innovators are more aggressive in R&D investment when I is higher. After rearranging I , the optimal innovation intensity, given the backward linkage μ and total market size π, is

$$I = \frac{\frac{(1-\lambda)}{2}}{[1-\lambda+\frac{\lambda}{\gamma}]} \tag{1.5}$$

From expression (1.5), I can derive a prediction about how backward linkages from the downstream foreign-owned firms affect the productivity of the foreign affiliate. I take the first-order derivative of $\ln I$ with respect to the backward linkage index $\ln\mu$ and derive equation (1.6)

$$\frac{d\ln I}{d\ln\mu} = \frac{\frac{\lambda}{\gamma}}{1-\lambda+\frac{\lambda}{\gamma}}(\beta_0-\beta_1) \tag{1.6}$$

In equation (1.6), since we know that $\frac{\frac{\lambda}{\gamma}}{1-\lambda+\frac{\lambda}{\gamma}} > 0$, the equation demonstrates that when the backward linkage μ changes, a change in domestic innovation intensity I depends on the sum of "market-size effect" (β_0) and the "spillover effect" ($-\beta_1$) . However, the sign of either β_0 or β_1 has not been identified through equation (1.6).

Identification of the "Spillover Effect"

The sign of $\frac{d \ln I}{d \ln \mu}$ would not be sufficient to identify the "spillover effect" (i.e., the sign of β_1) alone. In order to identify this effect, we need to have some additional information from other moments, in which β_0 and β_1 are interacted in a different way.

The moment that I choose here is the sign of $\frac{d \ln(\text{expected profits})}{d \ln(\mu)}$. It describes how the expected profit (1.7) changes as the backward linkage μ changes.

$$\ln(\text{expected profits}) = \ln(\gamma(1-\lambda)+\lambda)\pi + \beta_0 \ln(\mu) \tag{1.7}$$

Taking the first-order conditions for equation (1.7), we will get (1.8)

$$\frac{d \ln(\text{expected profits})}{d \ln(\mu)} = \frac{(1-\lambda)}{(1-\lambda)+\frac{\lambda}{\gamma}}(\beta_0 - \beta_1) + \beta_0 \tag{1.8}$$

The sign for market-size effect and spillover effect cannot always be identified; however, under some circumstances, these two effects can be identified. The following proposition introduces a case in which both effects can be identified.

Proposition 1: (The identification condition) When the sign of $\frac{d \ln I}{d \ln \mu}$ is positive and the sign of $\frac{d \ln(\text{expected profits})}{d \ln(\mu)}$ is negative, then we can identify a negative market-size effect and a positive technology spillover

effect.

Proof:

Since $\frac{\frac{\lambda}{\gamma}}{1-\lambda+\frac{\lambda}{\gamma}} > 0$, according to (1.6), when $\frac{d\ln I}{d\ln\mu}$ is positive, we know that $(\beta_0 - \beta_1)$ is positive, and we know that $\frac{(1-\lambda)}{(1-\lambda)+\frac{\lambda}{\gamma}}(\beta_0 - \beta_1)$ is positive, as well. Thus, given that $\frac{d\ln(\text{expected profits})}{d\ln(\mu)}$ is negative, according to (1.8), we would know that β_0 must be negative. Substituting β_0 into (1.6), we know that β_1 is negative, as well.

Intuitively, what is stated in Proposition 1 is that the only way to reconcile more innovation for lower profits is that it is easier to do the innovation, which implies a positive spillover from foreign firms to domestic innovators.

In this section, I used a simple innovation model that distinguishes the two possible channels through which the backward linkage of foreign-owned firms affects domestic innovation. In the next section, I will show that the cases described in Proposition 1 are consistent with Chinese firm-level data. This empirical result identifies a positive spillover effect in China, which suggests that backward linkages in Chinese industries may have a lasting effect on domestic innovators: foreign firms that have stronger backward linkages with domestic firms better prepare Chinese firms to compete with international competitors in the future.

1.5 Foreign ownership structure and its effects on domestic innovation

In section three, I demonstrate how the foreign ownership of foreign-owned firms will affect their backward linkages with the host country: Joint venture foreign-owned firms, rather than MNC affiliates, are the main source of backward linkages from foreign investment in a developing country. Harrison and Rodríguez-Clare [2009] survey a series of papers and conclude that foreign-owned firms tend to have higher productivity and may force domestic firms out of the market due to the crowding-out effect. Thus, combined with these two claims, I conclude that industries with a higher density of JV firms will have a higher foreign backward linkages with domestic firms, while the foreign backward linkage is weaker with a higher density of MNC affiliates.

In this section, I examine whether or not foreign backward linkage affects domestic firms' R&D decisions. I then use Proposition 1 in Section 1.4 to identify the channel through which foreign backward linkage affects domestic innovation. I will show that joint ventures, which exhibit a stronger backward linkage towards domestic firms, would encourage more firm innovation in their upstream industries. In addition, with the help of Proposition 1, I identify positive a technology spillover effect ($\beta_1 < 0$) for domestic innovation from foreign backward linkages. Together with fact that the foreign ownership structure in a foreign-owned firms will affect its backward linkage, the above result suggests that FDI policies regarding foreign ownership of firms could have a lasting impact on domestic innovation.

Construction of industry-level backward linkages

As previously described, foreign-owned firms with strong backward linkages may benefit their upstream suppliers' R&D. However, the absolute level of backward linkages that a particular industry receives will never be precisely measured. In order to compare the scale of backward linkages across industries, I proxy the the size of these backward linkages (μ) to an industry i using the JV and MNC densities in its downstream industries. As discussed in Section 1.3, at the industry level, the backward linkages to the industry are positively correlated with the density of JV firms, while negatively correlated with that of MNC affiliates.

I construct the MNC affiliates' (Joint-venture foreign-owned firms') density in downstream industries ($\mathrm{M}_{Downstream\, j}$ and $\mathrm{J}_{Downstream\, j}$– Rodriguez-Clare [1996] calls it "linkage coefficients") for all 81 three-digit manufacturing industries included in the 2007 Input-Output Table of China (National Bureau of Statistics, 2007).[13] Using these "linkage coefficients", I evaluate whether or not backward linkages from foreign-owned firms will generate positive spillover to related industries.

The linkage coefficients are constructed in three steps following Javorcik [2004]. In the first step, recall equation (1.1) , in which I calculated the foreign share for each firm i, which equals the ratio between foreign assets in firm i to its total assets.

$$\text{Foreign Share}_i = \frac{\text{Foreign Assets}_i}{\text{Total Assets}_i}$$

Then, in the next step, I calculated the foreign share for each industry j, (J_j for joint ventures and M_j for multinational affiliates), which captures the extent of JV firms' and MNC affiliates' presence in industry j. In particular, J_j is defined as foreign equity participation averaged over all JV firms in this industry, weighted by each firm's share Y_i in the sectoral output ($\sum_{i\in j} Y_i$).

$$\mathrm{J}_j \equiv \sum_{i\in j} \underbrace{\frac{Y_i}{\sum_{i\in j} Y_i}}_{weight\,for\,firm\,\mathbf{i}\,in\,industry\,\mathbf{j}} \times \underbrace{I(\text{JVC=1}) \times \text{foreign share}_i}_{foreigh\,share\,in\,firm\,\mathbf{i}}$$

The value of variable J_j increases with the output of JV firms, the number of JV firms and the share of foreign equity in these firms. Similarly, M_j is defined as follows:

$$\mathrm{M}_j \equiv \sum_{i\in j} \underbrace{\frac{Y_i}{\sum_{i\in j} Y_i}}_{weight\,for\,firm\,\mathbf{i}\,in\,industry\,\mathbf{j}} \times \underbrace{I(\text{MNC=1}) \times 100\%}_{foreigh\,share\,in\,firm\,\mathbf{i}}$$

Finally, in the last step, I calculate $\mathrm{J}_{Downstream\,j}$, which is the JV presence in the

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Year 2007 is the only year for which Chinese National Bureau of Statistics provides the input-output table for 3-digit industries

industries that buy from industry j. It is intended to capture the extent of backward linkages from JV firms in downstream industries of industry j. Since the dataset does not provide information about backward linkages at the firm level, I use the Chinese 2007 industry-level input-output information to calculate these backward linkage coefficients.

$$\mathrm{J}_{Downstream\,j} \equiv \sum \underbrace{\theta_{jk}}_{weight\,for\,industry\,\mathbf{k}} \times \mathrm{J}_k$$

,where the weight θ_{jk} is the proportion of industry j's output supplied to industry k, which is gathered from the 2007 Chinese input-output table.

$$\theta_{jk} \equiv \frac{\text{Input from industry j for industry k}}{\text{Total input for industry k}}$$

It is easy to show that the greater the JV presence in industries that buy from industry j and the larger the share of intermediates supplied to industries with a high JV presence, the higher is the value $\mathrm{J}_{Downstream\,j}$.

$\mathrm{M}_{Downstream\,j}$,which is the MNC presence in the industries that buy from industry j, is defined in a similar way.

$$\mathrm{M}_{Downstream\,j} \equiv \sum \underbrace{\theta_{jk}}_{weight\,for\,industry\,\mathbf{k}} \times \mathrm{M}_k$$

Effect of foreign ownership structure on firm-level innovation

First, I examine the effect of firm's foreign ownership structure at the industry level on firm's optimal innovation intensity, which is defined by $\frac{d\ln I}{d\ln\mu}$ in Section 1.4. To examine which sign of $\frac{d\ln I}{d\ln\mu}$ is consistent with the data, I regress the innovation intensity (I) on the log value of the backward linkage proxies (μ) based on equation (1.9).

$$(I_{Inno})_{ijt} = \beta_0 + \underbrace{\beta_1 \ln(\mathrm{M}_{Downstream})_{jt} + \beta_2 \ln(\mathrm{J}_{Downstream})_{jt}}_{\text{Scale of backward linkage}}$$

$$+\beta_3 * \eta_a + \beta_4 * \eta_j + \beta_5 * \eta_t + \varepsilon_{ijat} \tag{1.9}$$

In equation (1.9), the dependent variable $(I_{Inno})_{ijt}$ is the innovation intensity in firm i within industry j at time t. I measure innovation intensity as R&D expenditures divided by its production profits and then take the logarithm in a way similar to other variables in Section 1.3 ($I_{Inno} = \ln(\frac{\text{R\&D Expenditure}}{\text{Producation Profits}} + e^{-10})$). As defined in the previous subsection, $\mathrm{M}_{Downstream}\mathrm{jt}$ and $\mathrm{J}_{Downstream}\mathrm{jt}$ are the density of MNC affiliates and joint ventures in the downstream industries of industry j at time t. I also control for exogenous shocks that affect the affiliate's productivity. I control for area fixed-effects (η_a), industry fixed-effects (η_j) and time fixed-effects (η_t) using dummy variables.

The data sample for this regression includes all firms that are in the CASIF datasets between 2004 and 2007. Because information on innovation is available only for 2005-2007, and information on average human capital at the firm level is available only for 2004. I merge datasets from all these years into a panel dataset in which individual firms are identified using their tax-ID.

My estimation results from equation (1.9) using the CASIF dataset show that the share of backward linkages is positively associated with domestic innovation. Table 1.7 shows the estimation results. Column (1) in Table 1.7 shows that a 10% increase in the density of joint ventures is positively associated with a 0.69% increase in the innovation intensity of a firm in industry j. Although this effect is very small, but it is still significant.

In order to get more-robust results, in the next step, I estimate the following equation using both the Panel and Tobit methods:

$$(I_{Inno})_{ijt} = \beta_0 + \underbrace{\beta_1 \ln(\mathrm{M}_{Downstream})_{jt} + \beta_3 \ln(\mathrm{J}_{Downstream})_{jt}}_{\text{Scale of backward linkage}}$$

$$+\beta_5 MNC + \beta_6 JVC + \beta_7 * \ln(H)_i + \beta_8 * \ln(\frac{K}{Y}) + \beta_9 * \ln(TFP) + \beta_{10} * \ln(\text{Value added})$$

$$+\beta_{11} * S_{Export} + \beta_{12} * S_{Long-term} + \beta_{13} * \eta_a + \beta_{14} * \eta_j + \beta_{15} * \eta_t + \varepsilon_{jat} \qquad (1.10)$$

Column (2) of Table 1.7 summarizes the results from the above regression. It shows that a 10% increase in the density of joint ventures is positively associated with a 21% increase in the innovation intensity of a firm in industry j. However, a 10% increase in the density of MNC affiliates is negatively associated with a 9.6% decrease in the innovation intensity of a firm in industry j. As shown in Section 1.3, almost 90% of MNC affiliates and 80% of joint ventures are not engaged in any type of research and development. Thus, in column (3) of Table 1.7, I consider a Tobit model to incorporate this censoring effect into the data. The result shows that a 1% increase in the density of joint ventures or a 1% decrease in MNC affiliates in downstream industry j is positively associated with a 9.4% or a 5.2% increase,respectively, in innovation intensity, which is still significant but on a much larger scale. As interpreted in the previous section, this result shows that a positive correlation between backward linkages and domestic innovation does exist, which suggests that $\frac{d \ln I}{d \ln \mu} > 0$.

Table 1.7: Effects On Innovation (Firm Level Panel Data)

Dependent Variable:		I_{Inno}		I_2	
	Panel	Panel	Tobit	Panel	Tobit
VARIABLES	(1)	(2)	(3)	(4)	(5)
^{M}Downstream	**-0.002**	**-0.965*****	**-5.243*****	**-1.095*****	**-7.546*****
^{J}Downstream	**0.069*****	**2.131*****	**9.476*****	**2.418*****	**14.211*****
MNC		-0.519***	-4.893***	-0.486***	-3.922***
JV		-0.057***	-0.548***	-0.044***	-0.269***
Human Capital		2.178***	13.026***	2.317***	13.572***
$\ln(\frac{K}{Y})$		-0.235***	-0.735***	-0.287***	-1.549***
$\ln(TFP)$		-0.616***	-2.636***	-0.723***	-4.189***
ln(Value added)		0.487***	3.334***	0.464***	3.164***
S_{Export}		0.023***	0.197***	0.022***	0.166***
$S_{Long-term}$		0.033***	0.423***	0.033***	0.387***
Industry Dummy	No	Yes	Yes	Yes	Yes
Time Dummy	No	Yes	Yes	Yes	Yes
Area Dummy	No	Yes	Yes	Yes	Yes
Observations	610393	511762	511762	519780	519780
left-censored		–	457401	–	457451

*** p<0.01, ** p<0.05, * p<0.1

Not surprisingly, in addition to the main finding, I find one important firm feature that is associated with its R&D intensity: the firm's average human capital level. A 1% increase in the average human capital level (measured as in Bils and Klenow (2000): $H = e^{\phi(s)}$) is associated with a 13% increase in domestic innovation, which suggests that the innovation sector is, indeed, very skill-intensive. Finally, due to the fact that the firm's profit is always subject to great fluctuation, I introduce an alternative index for innovation intensity: $I_2 = \ln(\frac{\text{R\&D Expenditure}}{\text{Value Added}} + e^{-10})$, which is more stable for a firm over the years. In columns (4) and (5), I run a Panel Regression and Tobit regressions on this new innovation intensity index, and the results are still significant.

The main take-away from the regression of equation (1.10) is that positive effects from backward linkages on domestic innovations have been detected: industries with higher JV density in their downstream industries engage in more research and development. When an industry has a higher MNC density in its downstream industries, the reverse is true. This effect remains significant when I control for many aspects of firms or use different innovation indexes.

Effect of foreign ownership structure on firm-level profits

Although I find a positive effect of backward linkages on domestic innovation, as shown in the previous discussion, it is still insufficient to distinguish between the spillover effect and the market-size effect. In order to identify the signs of these two effects, one additional regression on the expected profit of firms must be run. In this section, I examine the effect of firm foreign ownership structure at the industry level on firms' profitability, which is defined by $\frac{d\ln(\text{Expected Profit})}{d\ln\mu}$ in Section 1.4. To examine which sign of $\frac{d\ln(\text{Expected Profit})}{d\ln\mu}$ is consistent with the data, I regress the production profit (P) on the log value of the backward linkage proxies (μ) based on equation (1.11).

$$(P)_{ijt} = \beta_0 + \underbrace{\beta_1 \ln(\mathrm{M}_{Downstream})_{jt} + \beta_2 \ln(\mathrm{J}_{Downstream})_{jt}}_{\text{Scale of backward linkage}}$$
$$+\beta_3 * \eta_a + \beta_4 * \eta_j + \beta_5 * \eta_t + \varepsilon_{ijat} \tag{1.11}$$

In equation (1.11), the dependent variable $(P)_{ijt}$ is the log value of the production profits of firm i within industry j at time t. I measure this profitability as the total value added of this firm minus its wage compensation, capital depreciation and operation and management costs. Again, I take the logarithm of this number in a way similar to other variables in Section 1.3 ($P = \ln((\text{Production Profits}) + e^{-10})$).

My estimation results from equation (1.11) using the CASIF dataset show that backward linkages are negatively associated with firms' profitability. Table 1.8 shows the estimation results. Column (1) in Table 1.8 shows that a 10% increase in the density of joint ventures or a 10% decrease in MNC affiliates in downstream industry j is positively associated with a 2% or an 1% increase, respectively, in the production profit of a firm in industry j. In column (2) of Table 1.8, I consider additional control variables on firms' features, and the results are still quite robust and become much more significant. The result shows that a 10% increase in the density of joint ventures or a 10% decrease in MNC affiliates in downstream industry j is positively associated with a 41% or 21% increase, respectively, in production profit. As interpreted in the previous section, this result shows a negative correlation between backward linkages and domestic profitability, which suggests that $\frac{d\ln(\text{Expected Profit})}{d\ln\mu} < 0$. As proposed in Proposition 1, combined with the previous results, we see that $\beta_1 < 0$, which suggests that the spillover effect exists.

Table 1.8: Effects On Firms' Profit (Firm-Level Panel Data)

Dependent Variable:		Production Profit		
	Panel	Panel	Panel (Demeaned)	Panel (Demeaned)
VARIABLES	(1)	(2)	(3)	(4)
${}^{M}\mathbf{Downstream}$	**0.100*****	**2.195*****	0.021***	2.014***
${}^{J}\mathbf{Downstream}$	**-0.271*****	**-4.186*****	-0.018**	-4.476***
MNC		-0.166***		-0.166***
JV		-0.119***		-0.120***
Human Capital		0.596***		-0.590***
$\ln(\frac{K}{Y})$		0.678***		0.675***
$\ln(TFP)$		1.307***		1.301***
ln(Value added)		0.783***		0.783***
S_{Export}		-0.008***		-0.008***
$S_{Long-term}$		-0.006***		-0.006***
Industry Dummy	No	Yes	No	Yes
Time Dummy	No	Yes	No	Yes
Area Dummy	No	Yes	No	Yes
Observations	5448901	462764	544891	462764
R-Squre: Within	0.0207	0.672	0.0002	0.649
R-Squre: Between	0.0000	0.893	0.0000	0.885
left-censored		–		

*** p<0.01, ** p<0.05, * p<0.1

The above regression results may seem counter-intuitive. There are two possible explanations for why the profitability of a firm decreases with backward linkages. The first one is a selection story: since MNC affiliates have less backward linkage with domestic firms, they may select only the best domestic firms to contract with. And these selected domestic suppliers may have an average profitability that is higher than that of firms with which joint ventures contract. This story will not affect the identification results. It still suggests that, although the benefit from R&D activities in firms that contract with joint-venture firms is lower than that in firms that contract with MNC affiliates, these firms are still willing to engage in more R&D activity.

However, what is worrisome is the second story, which is a fixed-effect story, is that the industries that intrinsically have a higher profit potential tend to have a higher density of multinational affiliates in their downstream industries. This story has the potential to collapse my theory because if the differences in profits are explained by the fixed effects, there is no longer enough information to tell the sign of $\frac{d\ln(\text{Expected Profit})}{d\ln\mu}$. In order to rule out this story, I demean the firm profits at the 3-digit industry level and regress this new variable - $\ln(\text{Relative Expected Profit})$[14] on the same dependent variables again. The regression result is reported in columns (3) and (4). According to these regressions, my results in the previous regressions are robust: backward linkages are negatively associated with firms' profitability. Finally, in these regressions, I report the within R-Square for each regression. Such a large within R-Square suggests that the change in downstream industries' MNC affiliate density over the years creates a substantial impact on the change in profits of domestic firms over the same period. Thus, I conclude that the industry-level fixed effects do not cause the benchmark regression result.

The results in this section suggest the scenario that the TFP in doing R&D is higher in firms that contract with joint ventures than in firms that contract with MNC affiliates. This result is important because it implies that policies that alter the foreign ownership structure at the industry level could actually raise the TFP in R&D activities, which will create persistent effects that enable domestic firms to compete with foreign competitors in the future.

1.6 Conclusion

Using Chinese firm-level operational and trade data, this paper answers, empirically, the questions: What FDI policies can increase domestic innovation? Is their effect persistent or transitory? I show the importance of foreign ownership structure in

[14] $\ln(\text{Relative Expected Profit}) = \ln(\text{Expected Profit})_i - mean(\ln(\text{Expected Profit}))$, since every variable is in log values, the demeaned value of firm-level profit is actually the relative expected profits in a certain industry.

determining the backward linkages of these foreign firms. Moreover, by examining how the foreign ownership structure affects firms' profitability and innovation intensity, I provide new evidence showing that joint ventures could help domestic firms in their upstream industry build their innovation capacities, which could enable them to compete with foreign competitors in the future.

From a policy perspective, my result emphasizes the importance of FDI policies regarding foreign ownership structure. In order to increase the backward linkages of foreign-owned firms, most government policies focus on protectionist actions—such as the "local contents act", the "infant industry protection act" or large subsidies to the local producers— in order to force foreign-owned firms to source locally. However, these policies will either decrease domestic innovation or have a transitory effect that fades out quickly when the government abandons these acts, which is consistent with the critiques of Rodriguez-Clare [2007], who claims that very few of these policies could help domestic firms gain a comparative advantage in doing innovation in the long run or could justify the costs to implementing the policies. So, the policies that favor to and encourage joint-venture foreign-owned firms could potentially be an appropriate option for helping the host country achieve a successful innovation sector in the long run at relatively lower costs.

2 DIVERGENCE IN DEVELOPING ECONOMIES, THE LINK BETWEEN TECHNOLOGY ADOPTION AND INDIGENOUS INNOVATION.

2.1 Introduction

During the late 1990s and 2000s, the developing economies in Asia began to diverge. Developing economies in this region—Korea, Taiwan and others such as Malaysia, which had been all considered role models for economic growth in the previous few decades—started to take different growth paths. Korea and Taiwan continued to have strong growth, while the economic growth in Malaysia quickly slowed down. During 1990-2010, when these countries had per capita GDP levels between 20% and 50% of the U.S level, Korea and Taiwan continued to grow at 7% percent per year; Malaysia, however, rapidly declined from its former 7% annual growth rate to less than 3% a year. According to Lucas Jr [1993]:

> "*The continuing transformation of Korean and Taiwan society is a "miracle". . . . [N]ever before have the lives of so many people undergone so rapid an improvement over so long a period and there isn't any sign that this catch up is near its end.*"

Natural questions are: Have developing economies such as Malaysia been "trapped"? And why is Korea's and Taiwan's experience different?

In order to answer the first question, the previous literature focuses on the impact of liberalization of international trade and foreign direct investment on developing nations. Two particular gaps contribute to the national income gaps between developing and developed countries. The first is the gap in factor productivity, and the second is the gap in factor accumulation. Romer [1993], McGrattan and Prescott [2009] and Alvarez et al. [2013] argue that FDI and the flow of ideas through international trade could largely reduce the productivity gap across countries; however, the theoretical literature, including Stokey [1988, 1991a,b], Matsuyama [1992, 1991], Young [1991] Chen [1992], Redding [1996], Ventura [1997], and Atkeson and Kehoe [2000], argue that the second gap is much harder to close under the presence of international trade and FDI. This literature demonstrates that when trade and FDI are liberalized, developing economies tend to specialize in industries with either lower spillover or lack of skill or capital accumulation, which would suppress factor accumulation in developing countries.

Although they are being able to explain most of the developing economies well, these theories fail to answer the second question: after the liberalization of trade and foreign direct investment, Korea and Taiwan not only significantly reduced the productivity gap with Western nations, but also succeeded in accumulating skills. These economies have achieved great success in the innovation sector; during 1980-2010, the per capita number of patents filed in the U.S from these two economies rose 500-fold from Korea and 40-fold from Taiwan. In 2010, these two economies filed twice as many patents per capita in the United State as did the developed world.[15]. With the rise of domestic innovation, Korea and Taiwan have been able to shift their specialization into sectors with high spillover and to encourage skill accumulation—and, hence, close the gap in factor accumulation. However, such structural change fails to happen in most developing economies. In Malaysia, the leading economy among the other developing nations, the per capita number of patents filed in the U.S is only 3% of that of the developed world, and, thus, the factor accumulation gap

[15] An average number taken by Japan, Germany, United Kingdom and France

between the developed world and Malaysia persists.

This paper aims to answer both questions in a unified way, by extending the existing theories. To understand how such divergence happens, I compare Korea and Taiwan with Malaysia and document the following new facts:

a) It is easier to adopt foreign technology in Korea and Taiwan than in Malaysia.

b) The major forms of FDI in Korea and Taiwan are joint-venture and Original Equipment Manufacturing (OEM), while the major form of FDI in Malaysia is through multinational affiliates.

The contribution of this paper is to develop a theory that explains why differences in technology adoption would lead to the differences in domestic innovation and, hence, differences in national income in the long run. In contrast to the general belief about technology adoption (appropriation), my theory maintains that a certain amount of technology adoption is beneficial rather than detrimental for the future domestic innovation of developing economies. In the previous chapter of this dissertation, I provide empirical evidence showing that more technology adoption takes place in joint-venture firms than in multinational affiliates.

The theory presented in this paper generalizes the technology capital theory of McGrattan and Prescott [2009] by adding two key features: a) Innovation productivity is increasing in the average education level; [16] and b) technology adoption takes place between FDI firms and their domestic partners or competitors and requires skilled labor to accomplish. My theory reveals a long-neglected "side-effect" of FDI policies: since technology adoption requires skilled labor, when FDI policy encourages technology adoption in a developing economy, returns to skills increase, which, in turn, encourages skill accumulation.

[16] This spillover effect has been studied intensively in the existing literature, such as Romer (1989) and Acemoglu and Angrist (2000).

A special dynamic Heckscher-Ohlin model is used to explore the divergence in developing economies. On the one hand, most developing economies begin with less skilled labor, which translates into lower innovation productivity and induces these economies to specialize away from the innovation sector; since the innovation sector is usually skill- intensive, a smaller innovation sector in developing economies implies less demand for skills and less skill accumulation than in the developed world. On the other hand, active technology adoption in some developing economies, such as Korea and Taiwan, may help a country break out of this "low-skill, low-innovation" equilibrium. In these economies, technology adoption serves as an alternative demand for skills. I show that the returns to technology adoption could be much higher than those of domestic innovation when the education level of these countries is low. Thus, when the developing country is poor, technology adoption may be more effective than domestic innovation in inducing skill accumulation. In the long run, if the demand for skill is high enough to shift the comparative advantage towards the innovation sector, then these economies will converge towards a "high-skill, high-innovation" equilibrium and catch up with the developed world.

Furthermore, I find that openness to FDI is complementary to technology adoption: the more open a country is, the more likely it is that this country will catch up with the rest of the world, given its ability to adopt technology. Lastly, I show that technology adoption will gradually phase out as innovation grows. The TFP rise in technology innovators compared to adopters leads to this process.

My paper is closely related to Alvarez et al. [2013] and McGrattan and Prescott [2009], which emphasize the flow of ideas through free international trade (foreign direct investment) and study its effect on domestic productivity improvement. Alvarez et al. [2013] start with the framework of Eaton and Kortum [2002] and Alvarez and Lucas [2007] and add a theory of endogenous growth, in which people get new, production-related ideas by learning from the people with whom they do business or compete. In Alvarez et al. [2013] , trade has a selection effect of putting domestic producers in contact with the most efficient foreign and domestic producers. McGrattan and Prescott [2009] introduce the concept of technology capital to the classical growth model and claim that the application of foreign technology capital will equate with the productivity of any open economies. However, neither Alvarez et al. [2013] nor McGrattan and Prescott [2009] discusses channels that encourage skill accumulation in developing economies, which is essential for a developing economy to break out of the "low-skill, low-innovation equilibrium." The main contribution of this paper is to show that FDI policy regarding the technology adoption rate has been found to have a lasting effect on skill accumulation and domestic innovation, which is essential to developing economies wanting to lift themselves out of the trap.

In the remainder of the theoretical section, I first study the motivating facts in section 2.2. In section 2.3 and section 2.4, I present a simple benchmark model that is similar to that of McGrattan and Prescott [2009], except for the externality in the innovation sector. In section 2.5, I include technology adoption in the benchmark model and derive four main results about technology transfer, adoption, innovation, the openness of a country and economic catch-up. Section 2.6 concludes.

2.2 Motivating facts

Economic slowdown commonly occurs in countries with per capita GDP that is between 20% and 50% of that of the U.S level. However, not all economies have been affected by such a slowdown equally. Two exceptions, Korea and Taiwan, have experienced continuous catch-up and reached 70% of the U.S per capita GDP level by 2010. In this section, first, I show that, in general, the growth divergence across developing economies indeed exists and that countries that catch up with the developed world are also successful in terms of domestic innovation. Second, in order to explore the features or policies that might contribute to the divergence across these countries, I use Korea, Taiwan and Malaysia as examples of countries that have "caught up" (Korea and Taiwan) and those that are "trapped" (Malaysia).

Divergence in per capita GDP

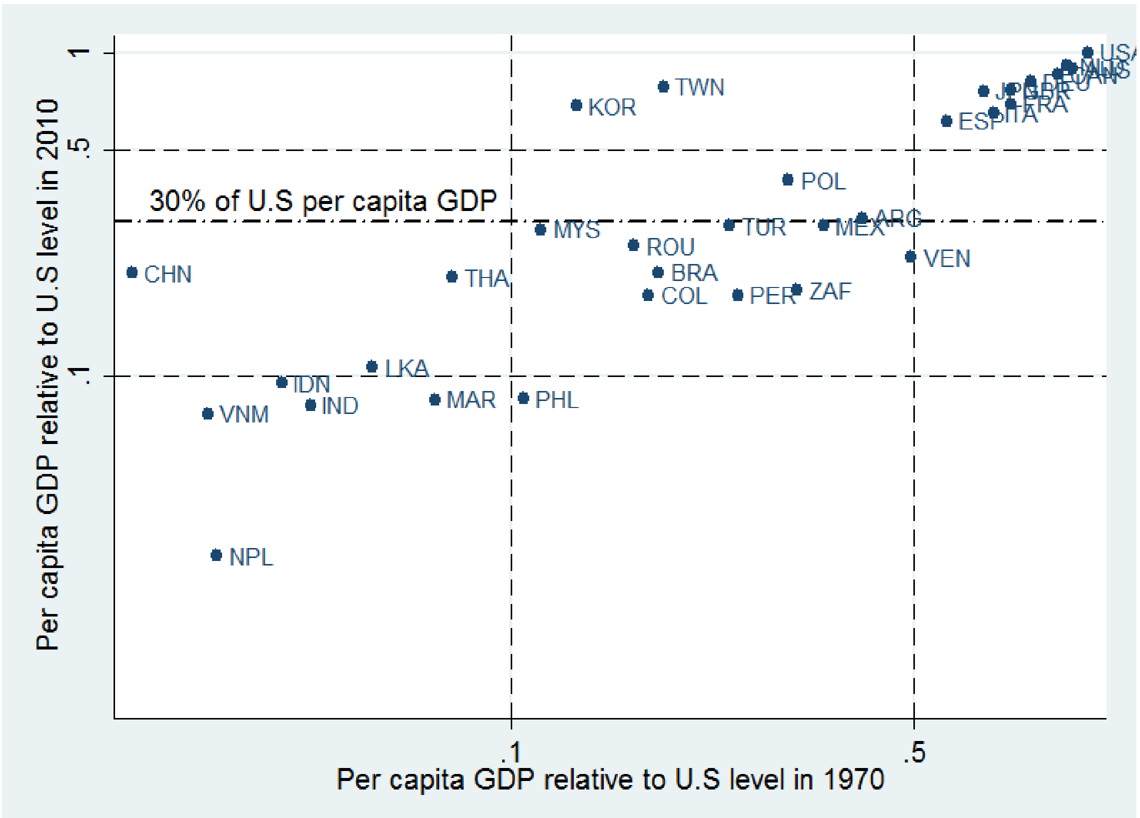
Figure 2.2 plots all countries with populations exceeding ten million in 1970 and open economies considered in Sachs et al. [1995][17]. On the horizontal axis is each country's per capita GDP relative to the U.S in 1970, while on the vertical axis is the per capita GDP of the corresponding country relative to the U.S level in 2010. Two critical values, 10% of U.S per capita GDP level and 50% of U.S per capita GDP level, have divided these countries into three groups. I refer to countries with per capita GDP less than 10% of the U.S level as low-income countries; countries with per capita GDP 10%-50% of the U.S level as middle-income countries; and countries with more than 50% of the U.S level as high-income countries. Countries in the diagonal blocks are countries that have stayed in the same group over the past 40 years.

Figure 2.2 show that the high-income countries tended to remain high-income during the past 40 years, while the low-income countries tended to move towards the middle-income countries. What is more interesting in this graph is the divergence within the middle-income group. I find that most middle-income countries remained middle-income during the past 40 days and have tended to converge to 30% of the U.S per capita GDP level, which is significantly lower than that of the developed world. However, this group contains two "super star" economies, which began at similar per

[17]China is not considered open economy as in Sachs et al. [1995]; however, given that China is already one of the largest exporters in the world, I consider China an open economy in the graph below.

capita GDP levels, but successfully moved to the high-income country category. The main focus of this paper is understanding what causes such divergence.

Figure 2.1: Relative Income Change During 1970-2010



Data Source: Penn World Table 8.0

Divergence in domestic innovation

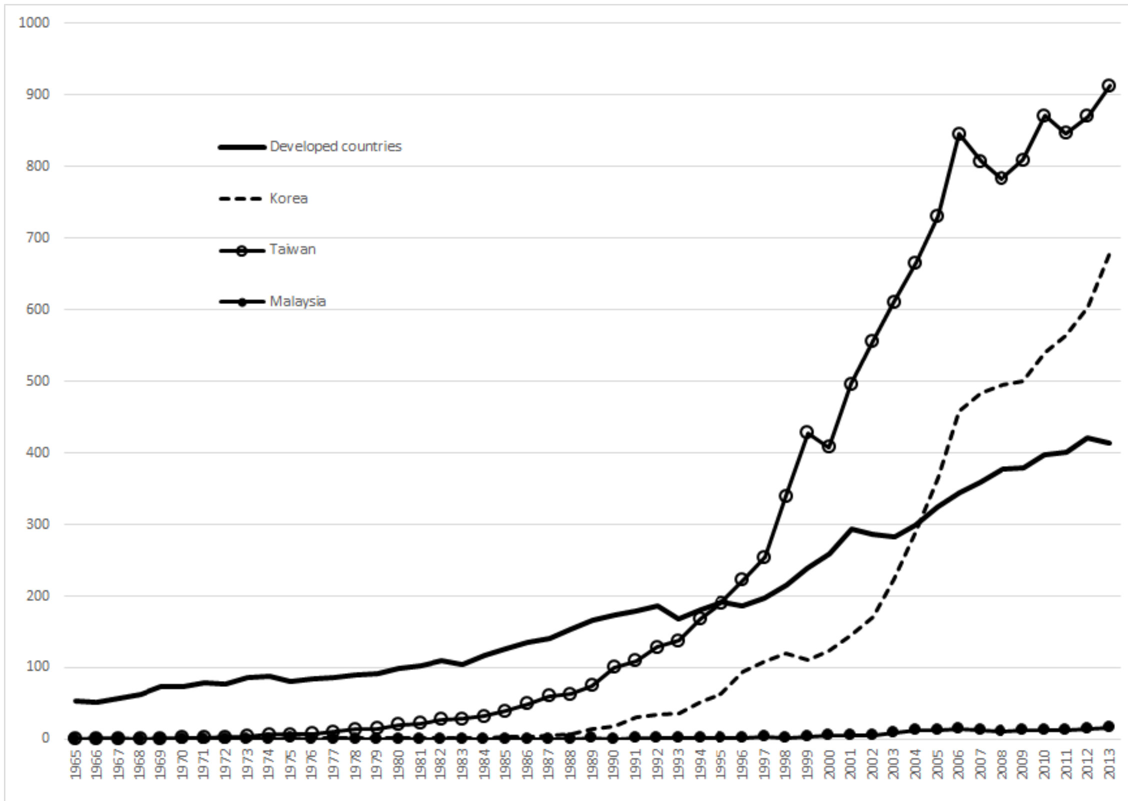
The second divergence across those middle-income countries is the divergence in domestic innovation. Since the domestic R&D expenditures of countries have been tracked only for a very limited period, I use the number of patent applications from these countries in the United States, per million population, as a proxy for the domestic innovation intensity of these countries. Using the patent data from the United

States Patent and Trademark Office (USPTO) (2013), I show that Malaysia, which caps all the countries that are stuck in the "middle-income region,"[18] tends to have low innovation rates, while Korea and Taiwan have had rapid growth in domestic innovation since the 1980s. Now, the domestic innovation rates in Korea and Taiwan are high, even compared with those of the developed world.

In Figure 2.2 below, the vertical axis is the log value of patent applications on a per capita basis. It is clear that in the early stages of their development, Korea, Taiwan and all other developing economies were well below the innovation intensity of the developed countries (UK, France, Germany, Japan). In the early 1970s, all these middle-income economies were starting from almost the same level. However, after 1985, Korea and Taiwan took off in patent applications, while Malaysia still lagged far behind. In 2013, looking at patent applications on a per capita basis, Korea and Taiwan did almost twice as much innovation as the developed world, while Malaysia reached only 3% of the level of the developed world.

[18] As shown in Figure 2.2, these countries include Argentina, Brazil, Colombia, the Philippines, Romania, Malaysia, Mexico, Peru, Poland, South Africa, Turkey and Venezuela.

Figure 2.2: US Patent Holdings, Per Million Population



Data Source: USPTO (2013) , Penn World Table 8.0

Difference between Korea and Taiwan vs. Malaysia

The three economies on which I focus are Korea and Taiwan in East Asia and Malaysia in Southeast Asian. These economies are politically stable and open to trade, and they have few barriers to using foreign technologies. According to most theories, these three economies should do equally well in their development. However, in this section, I document some new facts about these three economies that may shed light on their recent divergence.

Difference in technology adoption

The first finding about the difference between Korean and Taiwan and Malaysia is that Korea and Taiwan have a higher level of technology adoption than Malaysia. Assuming that genuine innovation should be registered worldwide, while adopted technology can be used only in the domestic market[19], I introduce a genuine-innovation index X_i , which is the fraction of patents registered in the U.S out of all patents filed in the home country i:

$$X_i = \frac{\#\text{ of patents registered in U.S from country i}}{\#\text{ of total domestic patents in country i}}$$

X_i should be low when a country encourages technology adoption.

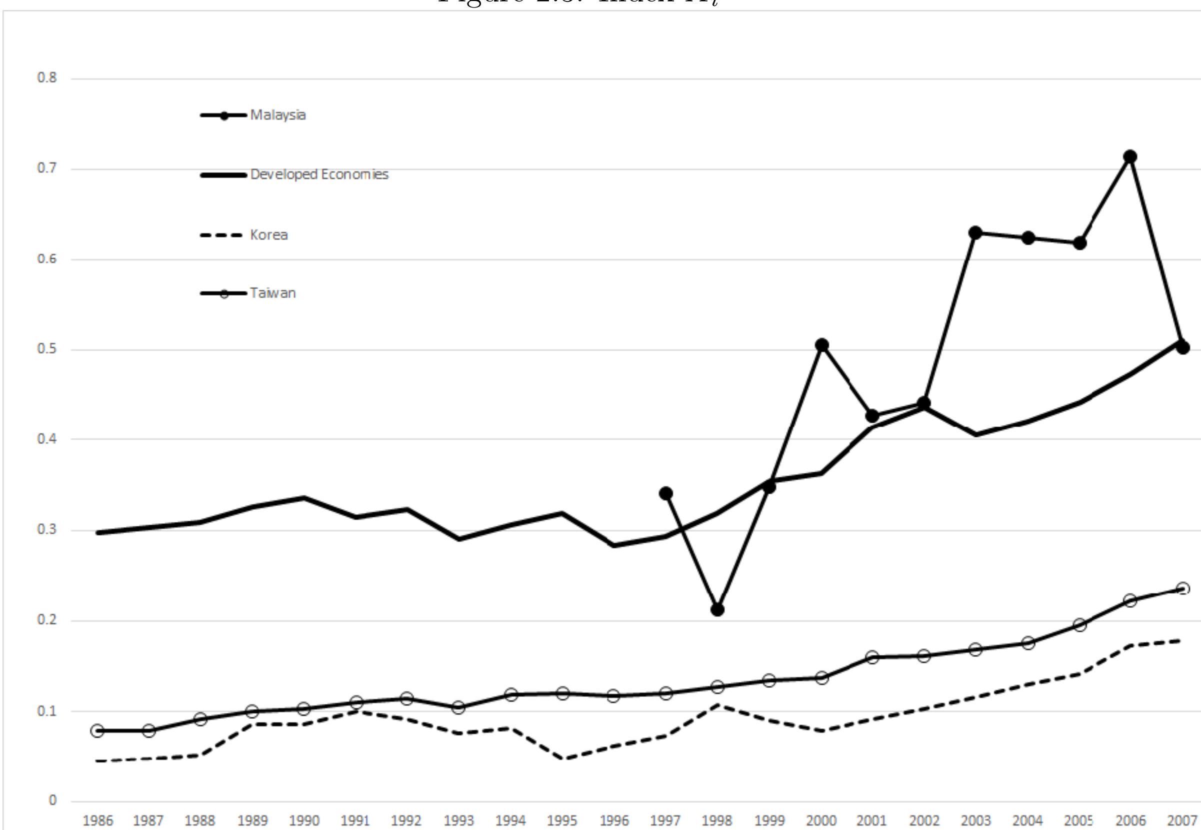
Figure 2.3 plots how index X_i changes over time in these countries compared with the developed world. The data show that the innovation index X in Korea and Taiwan is consistently and significantly lower than that in the developed world, which suggests that a larger fraction of patents applied in Korea are related to technology adoption and, thus, cannot be registered in the rest of the world. This fact suggests that Korea and Taiwan are engaging in more technology adoption than the developed world is. Some other literature, including Mathews [1996] and Enos [2008], studies the technology diffusion in Korea and Taiwan; they document that significant technology adoption exists in these two economies.

However, surprisingly, although Malaysia has low domestic innovation compared with developed countries and the two "East Asian miracles," the index X for Malaysia is very similar to that of the developed world—and sometimes higher. This fact sug-

19 Nelson and Rosenberg [1993], Kim [1997] and Hendricks [2010] find evidence that innovation in the developing markets is defined as products or processes new to the domestic market rather than brand new to the world.

gests that, although Malaysians are not active in innovation, they are not active in appropriating foreign technology either. Such a value of X suggests that the technology appropriation rate in Malaysia is similar to that in the developed economies, which is much lower than that in Korea and Taiwan.

Figure 2.3: Index X_i



Data Source: United Nations, Education, Scientific and Cultural Organization

Difference in FDI firms' ownership structure

Despite the fact that both East and Southeast Asian developing economies attracted a great amount of foreign direct investment during their takeoff periods, observers have noted that there is a large difference between the structure of this FDI in the two sets of countries: The Joint-venture/Original-Equipment-Manufacturing (JV/OEM) system is thriving in Korea and Taiwan, while Multinational-Corporation Affiliates (MNC) is the major form of FDI in Southeast Asian countries. According to Hobday [2000], these differences could be responsible for the difference in technology adoption in these countries. (See Appendix A)

Intuitively, the cost of technology adoption is lower if the adoption happens between a joint-venture firm or OEM buyer and its domestic partner because it is achieved through vocational training between managerial-level workers or through disclosing patented blueprints. The cost is higher if adoption takes place between MNC affiliates and their domestic competitor because these MNC affiliates tend to be "screwdriver plants" for exploiting low-cost labor. That is, they import intermediate goods from other parts of the world and sell their output out of the domestic market. Since little interaction takes place between MNC affiliates and domestic firms, technology adoption is less likely to occur. Domestic R&D staffs gain minimal experience, and their numbers do not grow. In the previous chapter of this dissertation, I provide direct evidence that joint-venture firms have stronger backward linkage with domestic firms and have positive spillover to domestic innovation capacity.

2.3 Model

The model studies why developing economies rarely catch up with the developed world and how the ability to adopt technology helps developing economies change their specialization pattern and catch up with the developed world.

In this and next section, first, I study the benchmark model, which does not have a technology adoption channel. I show why a developing economy that is closed to the rest of the world is poor in the first place; then, I allow this economy to open to the rest of the world and track its growth to see where it converges. In the section 2.3, I introduce technology transfer and adoption and discuss how developing economies are able to gain comparative advantage.

Model environment:

In the modeled world, there is a small developing economy, which I call "domestic." I use "foreign" to refer to the rest of the world, which is comprised of I identical small economies. In addition, the production technology, TFP and preferences are assumed to be the same across countries. In this section, I assume that the domestic country is closed to the rest of the world, while the countries in the rest of the world are open to each other with respect to both international trade and foreign direct investment.

There are two production factors, skilled and unskilled labor, used in two sectors of the model. The two sectors are the innovation sector, which creates the firm's technology capital and is skill- intensive; and the production sector, which uses existing technology capital to organize the production of final output and is unskilled-labor-intensive.

The technology capital is a firm's unique know-how from investing in research and development, brands, and organization capital. What distinguishes my model from the original technology capital model in McGrattan and Prescott [2009] is that in my model, firms do not accumulate technology capital using the final output; instead, they use output from the innovation sector.

A firm's technology capital is distinguished from other forms of capital in that a firm can use it simultaneously at multiple domestic and foreign locations. A multinational corporation (MNC) in a foreign country is able to exploit the value of the technology capital created in its home country by setting up operations in the host country. I refer to this as foreign direct investment (FDI). Thus, in my modeled world, FDI does not involve any actual flow of skilled or unskilled labor across borders; rather, it is just the flow of technology capital that increases productivity in low-productivity countries without hurting productivity in high-productivity countries.

The time in the model is discrete, t=1, 2, 3, ..., ∞. In each period, there is a mass 2L of workers living in each country. Workers live for two periods: at the first period, they work as unskilled labor and receive education; at the second period, they work as skilled labor. Workers consume final outputs in both periods to maximize their lifetime utility and receive education only in the first period.

Production

There are two sectors on the production side: the innovation sector produces new technology capital, while the final-production sector produces final output.

Innovation is undertaken by competitive technology firms in the innovation sector and final production is undertaken by competitive production firms in the final production sector. A production firm with m units of technology capital can divide its production into m separate steps; each step can be accomplished by a decreasing return to scale production plant. And firms aggregate the output of their plants. One might think that higher technology capital in a firm refers to a higher specialization level in this firm or that the firm is able to handle more-complicated tasks.

I will lay out the production process in country i in backward order: first, I will discuss the production technology at the plant level; then, I will aggregate production at the sector level; and, finally, I will consider the innovation sector to complete the benchmark model.

Plant-level production.

A plant produces one step in the entire production process. A plant in country i uses unskilled labor l_u (efficiency of unskilled worker is normalized to 1) and skilled labor l_s with human capital h (hl_s is their efficiency unit) to add value y_i to the entire firm's production process

$$y_i = A_i((hl_s)^{\alpha_P} l_u^{1-\alpha_P})^{1-\phi}$$

, where A is the total factor productivity in this country i , $1-\phi$ is the share of income accruing to the production factors and α_P is the share of skilled labor in final production.

Since I do not focus on the TFP difference across countries, I assume that $A_i = A$, which means all countries have the same plant-level production technology.

Each individual plant in country i will maximize its profit in country i. It takes as given the wage to unskilled labor w_i , the wage to the efficient unit of skilled labor w_{hi}, as well as the cost to run one unit of technology capital r_{Mi}.

$$\max_{h,l} A((hl_s)^{\alpha_P} l_u^{1-\alpha_P})^{1-\phi} - w_i l_u - w_{hi} h l_s - r_{Mi} \tag{2.1}$$

The first-order condition gives that:

$$(1-\alpha_P)(1-\phi)A((hl_s)^{\alpha_p} l_u^{1-\alpha_p})^{1-\phi}/l_u = w_i$$

$$\alpha_P(1-\phi)A((hl_s)^{\alpha_p} l_u^{1-\alpha_p})^{1-\phi}/(hl_s) = w_{hi}$$

These two F.O.C. solve a unique optimal choice of $l_u^*(w_i, w_{hi})$ and $(hl_s)^*(w_i, w_{hi})$.

Since the production sector is competitive, the final-production plants will make zero profit: $r_{Mi} = A((hl_s)^{\alpha_p} l_u^{1-\alpha_p})^{1-\phi} - w_i l_u - w_{hi} hl_s$.

Since all individual production plants use exactly the same production technology and face exactly the same factor prices w_i^* and w_{hi}^* , the optimal choice of unskilled labor $l_u^*(w_i^*, w_{hi}^*)$ and skilled labor $(hl_s)^*(w_i^*, w_{hi}^*)$ is the same across all plants in country i.

Besides domestic firms, foreign firms may also be able to set up production plants in country i through foreign direct investment. Let $\sigma_i \in \{0, 1\}$ measure the index of openness to this technology in country i. If $\sigma_i = 1$, country i is open to the use of foreign technology, and foreign plants will act exactly like domestic plants; otherwise, foreign direct investment is banned and no foreign plants are built in country i.

Aggregated production within a nation

Let the total amount of technology capital stock in country i be M_i and the available technology capital stocks in all countries be $\{M_j\}_{j=1}^I$. In equilibrium, since there is no additional cost to apply the technology capital in an additional place, all technology capital should be applied in as many places as possible. In particular, in country i, where the measure of openness is σ_i , the sum of all the technology capital that operates within its border will be: $M_i + \sigma_i \sum_{i \neq j} M_j$

Since each individual plant operates with one unit of technology capital, $M_i + \sigma_i \sum_{i \neq j} M_j$ plants will be established in country i, and each of them uses the same amount of skilled and unskilled labor in equilibrium. Let $H^P = hL_s^P$ be the aggregated efficiency unit of skilled labor used in the production sector, and L_u^P be the aggregated unit of unskilled labor in the production sector. Thus, the total value added in country

i in the competitive equilibrium, given openness parameter σ_i, will be

$$Y_i = A(M_i + \underbrace{\sigma_i \sum M_j}_{\text{Direct gain from openness}})^{\phi}((H_i^P)^{\alpha}(L_{ui}^P)^{1-\alpha})^{1-\phi} \tag{2.2}$$

Two important observations emerge here: first, the final output of a country is determined largely by its measure of openness (σ_i), and when the stock of foreign technology is large compared to the stock of domestic technology, openness to FDI will result in large productivity gains; second, at the aggregated level, the production sector preserves constant returns to the technology capital and production factors.

The innovation sector

The innovation sector produces technology capital. The R&D firms in the innovation sector produce new technology Y_M that adds to the existing stock of technology capital. The production function is a constant return to scale with respect to its two inputs: the efficiency unit of skilled workers $H^T = hL_s^T$ and the number of unskilled workers L_u^T. Since it is assumed that the innovation sector is more skill-intensive, the skilled labor share α_T would be higher than α_P. The productivity of the innovation sector receives positive spillovers from general knowledge level $\bar{h}$, which is defined as the average human capital of skilled workers.

The technology of the innovation sector is described in the following equation:

$$Y_{Mi} = A_T(\bar{h}_i)^{\psi}(H_i^T)^{\alpha_T}(L_{ui}^T)^{1-\alpha_T} \tag{2.3}$$

, where A_T is the innovation sector's productivity; and $\bar{h}$ measures the average education level of the country, which creates spillover $(\bar{h})^{\psi}$ to the firm.

The owners of technology capital in the innovation sector will rent out each unit of their technology capital to a specific final firm at a given equilibrium unit price R_M, and this final firm is allowed to apply this unit of technology capital all over the world.

The firms in the innovation sector take $\bar{h}$ and all prices as given, and they choose the efficiency unit of skilled and unskilled labor to maximize their profit:

$$\max_{L_u^T, H^T} p_M Y_M - w L_u^T - w_h H^T$$

, where p_M is the discounted rental income collected from one unit of technology capital.

At the aggregated level, $\delta_M M$ units of the existing technology capital have been outdated in each period. Thus, the updating rule of a corporation's technology capital would be:

$$M_i' = (1 - \delta_M) M_i + Y_{Mi} \tag{2.4}$$

Rest of the model:

Consumers/ Workers

In each period, there is a mass of 2L workers living in each country. Workers live for two periods, which, with respect to a particular individual, are labeled young (y) and old (o). Workers consume final output in both periods and maximize their lifetime utility.

$$\max_{c_t, c_{t+1}} u(c_t^y) + \frac{u(c_{t+1}^o)}{1+\rho}$$

After an individual is born, he acquires the basic knowledge of doing simple production. With this knowledge, he is able to work only as an "unskilled" worker. Young workers consume final output and spend money on education in order to learn advanced knowledge that prepares them to be skilled workers in the next period.

Young workers get old after a period, and when they are old, they lose the ability to do basic tasks. Old workers are able to work only as "skilled" workers, using the advanced knowledge that they have learned to solve complicated tasks. Since I have assumed that unskilled workers are equally efficient, I normalize the efficiency of unskilled workers to 1; the education level will affect only the human capital of the skilled workers.

It is assumed that at period 0, there are equal-sized groups of each age of workers, and that starting from period 0, on average, each individual has one child before he or she dies, implying that there is always a mass L of each age of worker.

There is a perfect financial market for individuals within a nation, but not across countries. An individual born at period t can borrow or save money at a given interest rate r_{t+1} in order to smooth his lifetime consumption. Thus, for any individual born at period t, the budget constraint is

$$c_t^y + e_{ht} + \frac{c_{t+1}^o}{1 + r_{t+1}} = w_t + \frac{h_{t+1} w_{ht+1}}{1 + r_{t+1}} \tag{2.5}$$

, where c_t^y is the consumption when the worker is young; e_{ht} is his spending on education; w_t is the wage level for unskilled workers during period t; and w_{ht+1} is the wage level for each efficient unit of skilled labor at $t+1$. When this worker is young, he gets paid by w_t, when he becomes old, his ability h_{t+1} to be a skilled worker is realized, and he gets paid by $h_{t+1} w_{ht+1}$; however, all he earned or spent at period

$t + 1$ will be discounted at an equilibrium rate r_{t+1}.

Education and human-capital accumulation:

Education is designed to help people gain the knowledge to be a skilled worker. An individual born at time t will imperfectly inherit such knowledge from his parents $(1 - \delta_M)h_t$ and he will spend e_t to improve it. The outcome of the individual's education is the combination of the two, and I assume that it takes a linear form at the moment:

$$h_{t+1} = (1 - \delta_h)h_t + A_e e_t^{\eta} \tag{2.6}$$

This naive human-capital accumulation function implies that to improve human capital in the future, the young individual forgoes current final outputs. In this sense, the human- capital accumulation is identical to capital accumulation.

Equilibrium:

In each period, market-clearing conditions require all households to use up the total final output Y in consumption, education investment or exports to other countries.

$$Y_{it} = C_{it} + E_{it} + NX_t$$

The skilled and the unskilled labor markets will also be cleared each period.

$$H_s^T + H_s^P = hL$$

$$L_u^T + L_u^P = L$$

Equilibrium results for a closed domestic economy

In this case, $\sigma = 0$ for the domestic country, and $\sigma = 1$ for all the foreign countries. I will solve the steady-state equilibrium for the closed economy and a symmetric steady-state equilibrium for all the foreign countries. I will use " * " to refer to variables in the rest of the world.

In the steady-state competitive equilibrium, all producers take prices as given and maximize their profit; all consumers take prices as given and maximize their utility subject to their budget constraint; all markets, including the final-good markets, the technology capital markets, and both the skilled and unskilled labor markets are cleared period by period. Finally, in addition, the equilibrium price that an innovator charges to the production firm R_M is consistent with the sum of residuals that a production firm owner could claim from the global market.

$$\sum_{j=1}^{I} \frac{\partial Y_j}{\partial M_i} = \sum_{j=1}^{I} r_{Mi}(M) = R_M \tag{2.7}$$

For the domestic country, since it is closed to the rest of the world, $r_M(M) = R_M$; for the foreign countries, since countries are symmetric,$I r_{M*}(M_*) = R_{M*}$

When solving the model at the above steady-state equilibrium (see Appendix), I generally do not get an analytical solution because the labor reallocation between the two production sectors will generate non-linear spillovers to the innovation sector. In order to obtain some analytical solution, I set $\alpha_T = 1$ and $\eta = 1$ and hold the other part of the model unchanged. Then, I obtain Proposition 1.

Proposition 1: When $\psi < \frac{(1-\phi)(1-\alpha_p)}{\phi}$, $\alpha_T = 1$ and $\eta = 1$, the domestic country has a lower steady-state technology capital stock (M), a lower steady-state education level (h), lower per capita output ($\frac{Y}{L}$), but a higher price for technology capital (P_M) than all the other foreign countries.

Proof: (In Appendix)

Intuitively, since the foreign country has a higher total technology capital stock, the measured productivity in the production sector is higher in that country. Due to the decreasing returns to scale technology and the fixed labor supply, the foreign country should have a higher education level that increases its skilled efficiency labor units. Finally, since the producer in the foreign country has higher productivity (technology capital) and better education, it should have higher output per capita.

2.4 Equilibrium results after the developing economy opens up

In this section, I study how the domestic country behaves after it turns from a closed economy to a open economy. At this stage,all economies are open to each other ($\sigma_i = 1$ for all $i \in I$). In this case, the TFP of the final production will converge across countries. This is because the total amount of available technology capital will be equalized across countries due to foreign direct investment. Hereafter, I will use "domestic economy" and "developing economy" interchangeably. I will use the term "developing economy" since at period 1, this economy is poorer than the rest of the world, but we would expect a large output growth in these countries in subsequent periods.

My model differs from that of McGrattan and Prescott [2009] in the following way: depending on education levels, countries may have different productivity in the innovation sector, which affects the equilibrium cost to produce technology capital. When $\alpha_T = 1$ and $\eta = 1$, the only equilibrium among all countries doing innovation in the steady state is that all countries are exactly symmetric with each other.

Other possible steady states require that either the developing economy or all foreign economies specialize in the production sector. Under both cases, the economy(ies) that end up with a positive-sized innovation sector will have comparative advantage in that sector. This is because in equilibrium, a country that operates in the innovation sector has a group of skilled workers with a higher education level than those in a country that specializes in the production sector— this, in turn, raises their productivity in the innovation sector. This advantage is self-reinforced, and it is similar to the "clustering effect." [20]

Proposition 2: When $\alpha_T = 1$ and $\eta = 1$, after the developing country opens up to FDI, labor productivity in the final-production sector will converge; however, national income levels may not converge.

Proof: (In Appendix)

As discussed earlier, three possible steady states can occur in the equilibrium. It is easy to show that under all three cases, the unskilled wage level w, the skilled wage on efficiency units w_h and the rental price of technology capital r_M will converge to the same level in all countries. In the symmetric steady state, productivity in both the innovation and production sectors converges, and countries will converge to the same national income level. However, if an economy specializes in unskilled-labor-intensive industries, even if it closes the productivity gap in the final production sector due to opening up to FDI, it is still not able to close the income gap between

[20] Audretsch and Feldman [1996] and Baptista and Swann [1998]

itself and the leading economy due to the lack of skill accumulation in that country. This occurs because the factor return will be equalized in the steady states, but economies with higher education levels will have higher wages for each skilled worker than the country that specializes in unskilled-labor-intensive industries. This model mechanism is similar to Atkeson and Kehoe [2000].

If the human capital production technology is non-linear ($\eta < 1$), we may not get the sharp distinction above. Depending on the size of spillover in the innovation sector ψ, it is possible that the developing economy also operates in both sectors. However, under all these cases, in the steady state, the developing economy still has less education e, a lower wage for skilled worker (w_h), a smaller innovation sector, but a higher skilled unskilled ratio (SUR) in the production sector. In the steady state, similar to the $\eta = 1$ case, the developing economy is still a net exporter of production output and a net receiver of foreign direct investment (net outflow of technology capital rents). The result is discussed again in the model simulation section.

Dynamics of the developing economy.

There are three steady states at which a developing economy may arrive, which correspond to scenarios of "no catch-up," "catch-up" and "overtaking," respectively.

From Proposition 2, we know that the production sector will finally converge in all scenarios. In order to know the per capita income of the domestic country, all we need to know is the size of its innovation sector. The larger the innovation sector in the developing economy in the steady state, the richer will be the country's economy.

Proposition 3: When $\alpha_T = 1$ and $\eta = 1$, after opening up, technology sector in developing economy decreases in size over time.

Proof: (In Appendix)

Intuitively, opening up will equalize the returns to technology capital across countries immediately. Noticing that the foreign countries have a lower price for technology capital than the "autarky technology price," the domestic technology rental rate decreases, and the returns to skilled workers in the innovation sector drops.

On the other hand, when an economy opens up, productivity in the production sector will increase because more technology capital raises the TFP of the production sector. Thus, the returns to skilled workers in the production section rises, and resources move away from the innovation sector towards the production sector. The stock of domestic technology capital would decrease over time since no more technology investment would be made in the developing economy.

This result is important because it implies that the lack of domestic innovation in developing economies is not because of their inadequate intellectual protection systems, but because their comparative advantage in the production sector discourages them from innovating. Thus, in order to encourage domestic innovation in a developing economy, the best way is not through strengthening IP protection, but through improving education, with the aim of creating a comparative advantage in innovation.

Corollary 1: The formerly closed economy will converge to the steady state that specializes in the final production sector.

Corollary 1 is directly deduced from Proposition 2 and Proposition 3. It suggests that the domestic economy will inevitably converge to the steady state where there is no innovation sector. This pessimistic result is consistent with the existing literature, which argues that the initial condition will determine the long-run steady state of a developing economy. In my case, two forces lock a developing economy into the unskilled-labor-intensive industry: first, after the country opens up to the rest of the world, the return on technology capital will drop dramatically due to the entry of foreign technology capital, which decreases technology capital investment and makes the developing economy move towards labor-intensive industries; second, the innovation sector creates positive spillover to itself, which increases productivity gaps and reinforces the comparative advantage of the developed world in the innovation sector. The above two effects predict a persistent income gap between developing economies and the developed world. It explains why developing economies rarely catch up and predicts the existence of a "middle-income trap."

2.5 Model with technology adoption

Section 2.3 and 2.4 discussed the benchmark model, in which developing economies would never catch up with the developed world. The main reason for such catch-up failure is that human capital does not accumulate in these countries. Due to the initial comparative disadvantage in the innovation sector, developing economies will specialize in the final production sector, which demands less skill in equilibrium; such a specialization pattern will, in turn, reinforce the comparative disadvantage in the innovation sector. In this section, I extend the benchmark model to explore how Korea and Taiwan, which were once developing economies, managed to accumulate skills and develop their own innovation sectors.

One important finding that may affect skill accumulation in Korea and Taiwan is that both economies were once the world's major technology adopters. Skilled workers - engineers and technicians- actively adopted technologies originated by the joint ventures or OEM firms in the earlier period of their economic growth. And these workers are the ones who finally brought about domestic innovation in Korea and Taiwan in a later period of their growth (Enos [2008], Mathews [1996]) . In other words, technology adoption in Korea and Taiwan has prepared sufficiently skilled workers to support the emergence of domestic innovation in these two economies.

The extended model will show that the innovation sector in a developing economy will operate in the steady state if and only if there is a sufficiently large technology adoption sector that creates enough demand for skills in this developing economy. This model extension will help us to understand the linkage between technology adoption and domestic innovation, which leads to economic catch-up.

Technology adoption

FDI firms' technology capital is subject to adoption by their domestic partners or competitors. Under different FDI policies, TFP for technology adoption could be different[21]. Intuitively, the adoption cost is low if the adoption is between a joint-venture firm and its domestic partner, which is achieved through vocational training between managerial-level workers[22], or between OEM buyer and OEM producer, which is achieved through disclosing patented blueprints. The adoption cost could be relatively high if it is between an FDI firm and its domestic competitors, which have no direct interaction.

Potential domestic adopters can adopt foreign technology in order to reap the profits by using adopted technology capital without paying rental costs to its original holder. Let c be the underlying TFP of technology adoption, which is assumed to be different across FDI firms. In order to adopt one unit of technology capital from an FDI plant that is associated with adoption cost c, a domestic innovator hires $h(\mu, c)$ efficiency units of skilled labor to accomplish the technology-adoption process. With probability μ, it will succeed in technology adoption and will be able to claim the

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McGrattan and Prescott (2013) document Micro evidence regarding Chinese FDI policy. They find that China pursues a "quid pro quo" FDI policy: The Chinese government encourages firms to "set the acquisition of technology as a high priority, especially in the fields of transportation, electronics and computers, telecommunications and energy.

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Cho [2013]

contemporary domestic profits by setting up its own plant that uses this technology capital; in addition, it may also able to apply the adopted technology capital in other countries that steal the world wide market share up to ϵ from the original technology holder. However, with probability $1-\mu$, it fails to adopt the technology and gets nothing.

For simplicity, the technology adoption cost $h(\mu, c)$ could be written in the form of $c * \hat{h}(\mu)$: it is increasing and convex in μ and linear in c, and the total expenditure in terms of final output associated with the adoption is $w_h c\hat{h}(\mu)$. The intuition behind this expression is that the more a domestic firm spends on learning from FDI firms, the higher the chance that it will make use of the knowledge from multinationals—i.e., adopted technology capital in our model. In particular, $\hat{h}(\mu)$ is assumed to take the convex expression in μ : $\hat{h}(\mu) = \frac{\mu^2}{(1-\mu)^\theta}$. This function has one property that is worth noting: $\hat{h}(\mu)$ is increasing and convex in the adoption odds (μ); when $\mu = 0$, $\hat{h}(\mu) = 0$ and $\hat{h}'(\mu) = 0$, as $\mu \to 1$, $\hat{h}(\mu) \to \infty$ and $\hat{h}'(\mu) \to \infty$. This property guarantees an optimal technology adoption intensity μ^* between 0 and 1.

A technology adopter that targets foreign technology capital will solve the following profit-maximization problem:

$$\max_{\mu} \underbrace{\mu(r_M + \epsilon * I * r_M^*) + (1-\mu) * 0}_{\text{Expected return on adoption}} - \underbrace{r_h h(\mu, c)}_{\text{Cost of adoption}}$$

The optimal technology adoption intensity μ solves

$$\mu(1-\mu)^{-\theta}(2 + \frac{\theta\mu}{1-\mu}) = \frac{r_M + \epsilon * I * r_M^*}{w_h c} \tag{2.8}$$

Notice that the LHS of equation (2.8) is increasing in μ ; and from (2.8) the RHS of equation (2.8) is increasing in the relative price of technology capital $\frac{r_M}{w_h}$ and decreasing in the adoption cost c. Intuitively, technology adoption will rise when it is easy to get access to the technology (c is low) or when the potential benefit of technology adoption is high relative to its labor cost $\frac{r_M+\epsilon*I*r_M^*}{w_h}$. Both factors will raise equilibrium profits from each unit of adopted technology capital. In order to get a clean analytical solution, I solve the model with $\theta = 0$, under this case, the optimal technology adoption rate $\mu = \frac{r_M+\epsilon*I*r_M^*}{2w_h c}$, and I also need to assume the technology adoption cost is high enough that guarantees $\mu^*(r_M, w_h) \in [0, 1]$.

At the aggregate level, suppose the total available technology capital to adopt is M, the size of the total efficiency units of skilled labor that works in the technology adoption sector will be

$$H^S(c, M, r_M, w_h) = M * h(\mu^*(r_M, w_h), c) \tag{2.9}$$

When $\theta = 0$, according to (2.8), the aggregate efficiency unit of skilled labor that works in technology adoption sector (2.9) would be

$$H^S(c, M, r_M, w_h) = \frac{M}{c}(\frac{r_M + \epsilon * I * r_M^*}{w_h})^2 \tag{2.10}$$

In the later simulation part, I simulate the model with $\theta > 0$, which guarantees an interior optimal solution for technology adoption μ^* at any given c.

Optimal μ^* solves min $\frac{2}{\mu} + \frac{\theta}{1-\mu} ==> \mu = \frac{1}{1+\sqrt{2/\theta}}$

Spillover effect from technology adoption towards innovation sector

The spillover effect of technology adoption towards the innovation sector is implied in equation (2.3) since the productivity of the innovation sector is proportional to the education level in the country:

$$h^{\psi} = \left(\frac{H^P + H^T}{L_s} + \underbrace{\frac{H^S(c, M)}{L_s}}_{\text{Spillover from technology adoption}} \right)^{\psi} \tag{2.11}$$

From (2.11), we see that the larger the size of the technology-adoption sector, the bigger the spillover effect from technology adoption towards innovation. Intuitively, engineers who have adopted some technology from foreign firms would find it easier to come up with new ideas than engineers who have never had access to foreign technologies. Thus, the more a country's skilled labor adopts foreign technology, the higher the country's productivity in its innovation sector will be. Equation (2.11), the core equation of this paper, explains, from the perspective of the model, why the technology-adoption sector in a developing economy is important for its later innovation and catch-up. Technology adoption in a developing economy will raise the demand for skilled labor and encourage the country to raise its education level over time, and these skilled workers create positive externalities for those who work in the innovation sector. As long as this process continues, the average education level $\bar{h}$ increases, which makes the innovation sector more productive over time.

Scale of spillover and technology adoption cost c

The scale of technology spillover from technology adoption is increasing with the efficiency units of skilled labor devoted to the technology adoption. According to (2.9), $H^S(c, M, r_M, w_h)$ is a decreasing function of the technology adoption cost c , and an increasing function of the total size of technology capital from FDI firms. Thus, the scale of spillover from technology adoption towards the innovation sector is decreasing in technology adoption cost c , and increasing in the total size of technology capital from FDI firms.

Long-run effect: conditions for innovation

Innovation finally happens if and only if the innovation productivity is high enough that the sales of one unit of technology capital p_M covers its unit cost $\frac{w_h}{h^{\psi} A^T}$. Reorganizing the inequality, we derived the condition for innovation:

$$h^{\psi} \geq \frac{w_h}{p_M A^T} \tag{2.12}$$

Proposition 4, The growth path of a developing economy is decided by its TFP in technology adoption ($\frac{1}{c}$). If there is a c^* that makes (2.12) holds with equality, for any scenarios with $c > c^*$, the developing economy never begins to innovate and, instead, specializes in the production sector forever; while for any $c < c^*$, the innovation sector will start to operate in this country during the transition path.

Proof:

According to (2.12) The innovation would start to innovate if and only if

$$\left(\frac{H^P + H^T}{L} + \frac{H^S}{L} \right)^{\psi} \geq \frac{w_h}{p_M A^T}$$

After we rearrange the equation, the condition for active innovation in the steady state is:

$$H(M,c) \geq \left(\frac{w_h}{p_M A^T}\right)^{\frac{1}{\psi}} L - (H^P + H^T) \tag{2.13}$$

According to the profit maximization problem of innovators in the developed economies, the equilibrium technology capital price equals to $p_M = \frac{w_h^*}{A^T (h^*)^{\psi}}$, thus (13) would reduce to

$$H(M,c) \geq \left(\frac{w_h}{w_h^*}\right)^{\frac{1}{\psi}} \bar{h}^* L - (H^P + H^T)$$

We know that when $\eta \leq 1$, the equilibrium wage for skilled efficiency units is lower in the developing economy $w_h \leq w_h^*$ and which in turn raises the equilibrium Skilled-unskilled-ration in the production sector in the developing economies $H^P > H^{*P}$. In an other word, the RHS of the (2.13) is capped by $\bar{h}^* L - H^{*P}$. On the other hand, from (2.10), we also know that at the steady state, $H^S(c, M) = \frac{M}{c}(\frac{r_M(1+\epsilon * I)}{w_h})^2$. It is clear to see that, the LHS of the equation is monotonically decreasing in c. If there is a $c^* \in (0, \infty)$, that makes (2.13) holds with equality, and for every $c < c^*$, $h^{\psi} > \frac{w_h}{p_M A^T}$ while for any $c > c^*$, $h^{\psi} < p_M A^T$. Q.E.D

The above proposition describes scenarios that a developing economy may or may not engage in domestic innovation. One can clearly observe that under this two-sector model, TFP for technology adoption is important for domestic innovation in a perfectly open developing economy. Intuitively, this is because the domestic innovation sector is inefficient compared with its foreign competitors when the education level in the country is low; thus, low technology adoption will not necessarily bring skilled labor back into the laboratory for real innovation. On the other hand, the process of technology adoption acts as a training camp for domestic skilled laborers, and the demand of adopting foreign technology pushes up the domestic education level, which, in turn, generates a huge spillover to the innovation sector and will make domestic skilled labor capable of doing real research later.

Proposition 5: When the innovation sector has been activated, resources move out of technology adoption towards innovation over time.

Proof:

Innovation begins when (2.12) holds with equality. However, starting from there, holding everything else constant, if an efficient unit of skilled labor in the innovation sector (H^T) moves up by ε , then the productivity of the domestic innovation sector becomes more efficient and, thus, the comparative advantage will attracts more efficient unit of skilled labor H flow to the innovation sector, and H^T will keep rising.

According to (2.10), the growth of H^T creates two effect on the value of H^S:

On the one hand, higher H^T raises the domestic production of technology capital M_i in the equilibrium, which decreases the equilibrium rental price of technology capital r_M. On the other hand, as H^T gets accumulated, the productivity of the domestic innovation sector increases, which raises the equilibrium w_h.

From equation (2.8) , we know that H^S decreases as H^T gets accumulated. (Q.E.D)

Proposition 5 explains the structural transformation from technology adoption towards indigenous innovation that has happened recently in the most advanced developing economies. It shows that technology adoption activity decreases as the country becomes richer. This process takes place because as human capital in this country gets accumulated, the innovation sector productivity rises, which raises the equilibrium skilled wage w_h; thus, the underlying cost of technology adoption increases, and it then becomes crowded out. We should observe a flow of skilled labor into the innovation sector and out of the technology-adoption sector.

Interaction between openness and technology adoption

In the previous sections, I assumed that every country is either open or closed to the rest of the world ($\sigma \in \{0, 1\}$), in this section, I discuss this model under the general framework: $\sigma \in [0, 1]$. Now, σ_i represents the relative productivity of foreign operations within the border of country i. [23]. Similarly to our previous case, if $\sigma_i = 1$, then country i is totally open to the use of foreign technology capital within its borders. If $\sigma_i = 0$, then country i is totally closed to that use.

Suppose that, at period 0, all foreign countries are open to each other at openness measure σ^*, and the domestic country is closed to the rest of the world ($\sigma = 0$). At period 1, the domestic country opens to the rest of the world at openness measure σ , and its FDI policy requires a technology-transfer TFP: c.

Proposition 6. The required technology-transfer TFP (c^* as in proposition 5) is decreasing in the measure of openness σ.

Proof:

In order to get c^*, I need to figure out the scale of the spillover effect from the technology-adoption sector towards the innovation sector. And the scale of the spillover is determined by the number of efficient units of skilled labor that is devoted to technology adoption H^S.

In order to do find out how H^S changes in σ , I modify equation (2.9) using the first order conditions on H^P and M.

[23] McGrattan & Prescott 2009

$$H^S(c,M) \propto \left(\frac{\sigma^{\frac{1}{\phi}} H^P(\sigma)}{(M_i + \sigma^{\frac{1}{\phi}} \sum_{i\neq j} M_j)}\right)^2 (\sum_{i\neq j} M_j)/c \tag{2.14}$$

Thus, for any given $\hat{c}$ and M, the demand for technology adoption human capital $\overline{H^S}(c,M)$ is increasing in

$$\underbrace{\ln\left(\frac{\sigma^{\frac{1}{\phi}}}{(M_i + \sigma^{\frac{1}{\phi}} \sum_{i\neq j} M_j)}\right)}_{\text{Return on adopted technology effect}} + \underbrace{\ln(H^P(\sigma))}_{\text{Production human capital}} \tag{2.15}$$

It is easy to see that return on adopted technology is increasing in σ, which suggests a higher return from technology adoption when the country is more open to the rest of world, holding everything else constant. This effect comes from the fact that adopted foreign technology capital can be used in a more efficient way when σ is large.

In addition, the effect from the production is also positive. Holding everything else constant, due to the decreasing returns to scale of production technology, the steady-state skilled efficient units in the production sector H^P is increasing in the TFP of the production sector, which is increasing in σ. This effect gives higher domestic profit for adopting one unit of technology capital from foreign technology owners.

Since both effects are increasing in σ — which suggests that the innovation sector receives more spillover (a larger $H^S(c,M)$) when σ is large — as discussed in proposition 5, a smaller adopting TFP $\frac{1}{c^*}$ is required to foster domestic innovation in the later stage. (Q.E.D)

This result tells us the FDI policies regarding technology transfer will work more effectively when a country is relatively more open than the rest of the world.

2.6 Conclusion:

In this paper, I investigate the difference between Korea and Taiwan, on the one hand, and Malaysia, on the other, and document the fact that technology adoption has been more prevalent in Korean and Taiwan than in Malaysia. Based on this finding, I modify the existing open economy growth theory to incorporate a possible link between technology adoption, domestic innovation and economic catch-up.

I describe the model's findings by summarizing them. In this model, since foreign technology is fully accessible by any open economy, the main engine of growth is the accumulation of the human capital, and the main source of differences in living standards among nations is differences in human capital. However, due to the initial scarcity of human capital, developing economies tend to divert away from industries that intensively use human capital—i.e., the innovation sector. In order to avoid the "low-skill, low-innovation" trap, technology adoption seems to be, by far, the best approach for these developing economies. This is because technology adoption will raise the demand for skilled labor, which encourages education, raises the productivity of the innovation sector and changes the comparative advantage of the developing economy in the long run.

To increase the scale of technology adoption, one lesson taught by Korea and Taiwan is their choice of foreign direct investment. I have observed that FDI firms in Korea and Taiwan take the form of joint ventures and OEM in the previous chapter, and I find evidence that FDI through these types of firms transfers more technology than FDI through multinational affiliates.

Of course, this paper does not exhaust all the channels that might encourage domestic innovation in Korea and Taiwan. And it also does not consider how foreign firms may respond to policies that encourage technology appropriation. Future effort should be made in these two directions.

Finally, as Robert E. Lucas so aptly stated: "*If we know what an economic miracle is, we ought to be able to make one.*"

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APPENDIX A

APPENDIX FOR CHAPTER 1

Definitions of the Chinese Customs Regimes

Table A.1 provides a detailed description of all Chinese Customs Regimes. In the data, a trade is considered processing trade when the trade regime code equals 14 or 15.

Table A.1: Definitions Of The Chinese Customs Regimes

Regime code	Regime name	Definition
10	Ordinary trade	Unilateral imports or exports through customs
11	International aid	Aid or donations given gratis between governments or by international organizations.
12	Donation by overseas Chinese	Donations given by overseas Chinese or compatriots in Hong Kong, Macau or Taiwan.
13	Compensation trade	Imports of equipment supplied by foreign firms or by using foreign export credit under a contractual arrangement for the supplier to recover the cost with the subsequent exportation of products in installment.
14	Processing and assembling	The type of inward processing in which foreign suppliers provide raw materials, parts or components under a contractual arrangement for the subsequent re-exportation of the processed products. Under this type of transaction, the imported inputs and the finished outputs remain property of the foreign supplier.
15	Processing with imported materials	The type of inward processing other than processing and assembling in which raw materials or components are imported for the manufacture of the export oriented products, including those imported into Export Processing Zone and the subsequent re-exportation of the processed products from the Zone.
16	Goods on consignment	Goods traded by arrangement in which a seller sends goods to a buyer or reseller who pays the seller only as and when the goods are sold. The seller remains the owner (title holder) of the goods until they are paid for in full and, after a certain period, takes back the unsold goods.
17	Border trade	Petty trade carried out in the border towns of China, between the departments or enterprises designated . by the governments of provinces or autonomous regions and the border towns on theother side, as well as to the mutual market trade between the border inhabitants of the two neighboring countries
18	Equipment imported for processing trade	Imports of equipment for processing trade activities under the customs
19	Contracting projects	regimes of processing and assembling and processing with imported Materials.
20	Goods on lease	Exports of equipment or materials to be used for China-invested turnkey projects or constructing projects.
21	Equipment/materials investment by foreigninvested enterprise	Imports or exports under the financial lease arrangement with the duration of the lease for one year or more.
22	Outward processing	Imports of equipment, parts or other materials by a foreign-invested enterprise as part of its total initial investment.
23	Barter trade	Exports of raw materials, parts or components under a contractual arrangement for processing or assembling abroad and the re-imports of the processed products.
24	Duty-free commodity	Exported goods directly exchanged with the equivalent in imported goods without any currency medium.
25	Warehousing trade	Duty-free import commodities sold in the specific shops to the specific individuals on payment of foreign currency according to the specific customs regulations.
26	Entrepot trade by bonded area	Goods imported into or exported from the customs bonded warehouses located outside a Bonded Area.
27	Others	Others

Source: Upward and Wang and Zheng (2010), Table A-3 Upward et al. [2010]

Data Merge

Merging the CASIF and CCTS datasets allows me to link firm production with firm trade. Since the CASIF and CCTS data do not use consistent firm-identification numbers, following Tian and Yu (2012), I use two matching criteria. The first criterion is firm name, which is a reliable match variable, as it is ruled that no firms can have the same name in the same administrative region. The second criterion is used as a complimentary method: I use the last seven digits of the firm's telephone number and its post code to identify firms having different names in different datasets. The matched result is summarized in Table A. One can see that the matched firms consist of a third of all CASIF firms.

Table A.2: Matched Results

	Simple Match	CASIF:Total	Matched Ratio
	Number of Firms	Number of Firms	Percentage
2004	63,966	202,007	31.7%
2005	65,879	204,965	32.1%
2006	71,108	232,842	30.5 %

One natural question is whether or not the merged sample is biased from the original sample. Thus, I compare three major statistics between the merged sample and the original sample. The result is summarized in Table A. I would say that these statistics are very similar, so I consider the sample to be unbiased.

Table A.3: Merged Dataset

	Combined with export	CASIF with export
Employees (Log)	5.24	5.19
	(1.16)	(1.15)
Total sales (Log)	10.74	10.52
	(1.36)	(1.36)
Value added per worker (Log)	4.11	3.96
	(1.13)	(1.09)

APPENDIX B

APPENDIX FOR CHAPTER 2

Differences in FDI firms' ownership structure

In order to gain meaningful information on how foreign technology shapes the different growth patterns of Korea, Taiwan and Malaysia, I focus on foreign impacts on the electronics industry. There are two main reasons for focusing on electronics. First, due to the backward technology position of these economies in the early periods, foreign technology transfer and foreign investments heavily influenced the development and growth of the electronics industry. Second, the electronics industry accounts for a large portion of both GDP and exports in these countries. The electronics industry is the most important industry in the three countries being compared, and the export of electronics accounts for around a quarter to a half of their total exports.

The JV/OEM system in the East Asian economies A joint venture (JV) is a business agreement in which the parties agree to develop, for a finite time, a new entity and new assets by contributing their own resources; original equipment manufacturer (OEM) is a term used when one company makes a part or subsystem that is used in another company's end product. From these definitions, I infer that technology transfer occurs within these two systems. In the joint-venture cases, researchers of the local firms would cooperate with foreign experts and learn directly from them. In terms of OEM, foreign firms would provide the blueprint for their product design, and it is very likely that a domestic OEM firm could learn from it.

Electronics industry in Korea In South Korea, the government fostered the growth of a small number of large oligopolistic firms with sufficient resources to overcome entry barrier in electronics. The country built three big firms to dominate the industry—Samsung, LG and Daewoo—which are capable of doing business with foreign multinationals.

"*In the 1960s, U.S. firms, including Motorola, Signets, and Fairchild, began to assemble chips with these local oligopolistic firms through OEM. Japanese firms, such as Toshiba, and Korean-Japanese Joint ventures, such as Samsung-Sanyo and LG-Alps Electronics later began OEM relationships with these South Korean oligopolistic firms.*" (Suh, 1974, pp.17-19).

During the takeoff period in the 1970s, there was a substantial increase in the share of local and joint ventures. Their production increased from only $45 million in 1968 to $3.3 billion in 1979, while exports grew from $20 million to $1.8 billion during the same time. (Hobday [2000])

In the later phase, during the 1980s, the share of foreign ownership in electronics fell considerably. Japanese firms, such as Matsushita, Sanyo and NEC, withdrew from joint ventures, as the Korean government encouraged them to leave. Korean Chaebols—large, conglomerate family-controlled firms—became the dominant force for production and export. (Hobday [2000])

Electronics industry in Taiwan: In the 1960s, the Taiwanese electronics industry benefited considerably from Joint ventures and foreign OEM buyers. A large number of local firms rushed in to supply them with goods and services, leading to a thriving subcontracting system. Foreign buyers led to backward linkages with local Taiwanese producers and raised the quality of exports. During the 1970s and 1980s, companies such as Philips, RCA, IBM, DEC, NEC, Sanyo, Sharp, Matsushita, Epson, and Hewlett-Packard eased Taiwan's entry into the computer industry by applying the OEM system to source local Taiwanese firms. By the early 1990s, the world's leading computer companies were highly dependent on Taiwan for high-resolution monitors, keyboards, printed circuit boards, graphics cards and printers. (Hobday [2000])

Table B.1 is a sample of Taiwanese OEM firms. Most big firms conducted business with Taiwanese firms through the OEM system in the 1990s.

Table B.1: Taiwanese OEM Partnerships In 1990s

OEM buyer	Product	Taiwanese Producer
Apple	Monitor	Tatung
	Laptop	Acer
Compaq	Monitor	ADI,Teco
	Laptop	Inventec
	PC	Mitac
Dell	Monitor	Lite-on,Royal
	Laptop	Quanta
	Motherboard	GVC,Lun Hwa,FIC
IBM	Monitor	Sampo
	Laptop	ASE
	Motherboard	GVC,Lun Hwa,Elite
Gateway	Laptop	ASE
	Monitor	Mag
Sharp	Laptop	Twinhead
NEC	Monitor	Tatung
	Motherboard	Elite
Hitachi	Monitor	Acer
	Laptop	Twinhead
Epson	PC	Unitron
	Laptop	ASE,Compal,Twinhead
Philips	Laptop	Kapok

OEM= Original equipment manufacuture
Source: Market Intelligence Center,Electronic Business Asia, December 1995.

To recap, the growth experiences in Korea and Taiwan share a common route: they both started with JV and OEM cooperation with foreign technology leaders. In the early stages, domestic firms learned from these technology leaders, gained experience, developed their own R&D staffs, and, finally, quit the joint ventures and brought out their own technologies.

The Multinational-Led development in Malaysia Malaysia is one example of multinational-led growth in Southeast Asian. Thailand and the Philippines share a similar growth pattern but at a much lower per capita GDP level.

The electronics industry in Malaysia began in the 1960s under the country's new trade policy, somewhat later than in Korea and Taiwan. Matsushita of Japan was the first major foreign investor, in 1966. Other firms from Japan, the U.S. and Europe all rushed in and assembled radios, TVs and some simple components of electronic appliances. These industries grew rapidly, as MNCs benefited from low-cost labor, as well as from the ten-year, tax-free "pioneer" status. During 1981-1990, electronics exports grew more than sixfold, from $3.2 billion to $22.1 billion in 1990. In 1987, electronics became Malaysia's largest export sector. (Hobday [2000])

However, Malaysia did not experience the same industry growth as its East Asian counterparts; in 1986, the share of chip testing and assembly, which is considered a typical "screwdriver" task, accounted for 82 percent of Malaysia's total electronics exports. Although this number started to decline somewhat later, it still accounted for almost 50 percent throughout the 1990s.

Table B.2, based on a research in 1995, is a representative sample of major Malaysian Electronic producers. The total sample amounted to around US$7.3 billion production (approximately 30 percent of total electronics exports in 1995). From this sample, we see that the dominant firms in the Malaysian electronics industry are MNC affiliates.

Table B.2: Major Electronics Producers In Malaysia

Firm	Ownership	Employment
Intel, Penang	USA	2600
Motorola	USA	13000
Matsushita	Japanese	24700
SEH (Shin-Etsu)	Japanese	1350
Sony Electronics	Japanese	8000
Sony Mechatronics	Japanese	2900
Centronix	Taiwanese	700
Inventec	Taiwanese	3000
Grundig	German	900
MEMC	German	640
Siemens	German	1560
Philips/JVC	Dutch/Japanese	3190
Likom	Local	3300
Sapura	Local	4500
UNISEM	Local	1100

Data Source: Management Decision 34/9 [1996] 71–81

To summarize the empirical evidence about Korea and Taiwan and Malaysia, I find differences in technology adoption as well as in the FDI policies regarding ownership structure. The countries with the JV/OEM system tend to have higher technology transfer.

Solve for a symmetric steady-state equilibrium

In a "symmetric" steady-state equilibrium, there are two types of countries, c and o (c for closed and o for open), in the world. All open economies behave identically.

The consumers take as given the wage of being a skilled or an unskilled worker and maximize their lifetime utility subject to the budget constraint. In this simplified model, one kind of "saving" that a consumer carries over to the future is his human capital H . In the steady-state equilibrium, the Euler equation holds for both the closed and the open economy. $i \in c, o$.

$$1+\rho = 1+r^* = w_h^* \tag{B.1}$$

Production firms take all prices $\{r_M^*$,w_h^* and $w^*\}$ as given , maximizing their profit by renting the optimal amount of technology capital m_j from the innovators and hiring a skilled and unskilled labor force in the factor market. In the previous argument, I showed that all plants choose the same amount of skilled and unskilled labor in equilibrium, and the size of the firm does not matter for that choice.

Thus, at the aggregate level, the optimal solution of individual firms in the production sector in country i is identical to the solution that a large profit-maximizing firm that hires an entire unskilled population would optimally choose. Let $y_i = \frac{Y_i}{L_i}$, $m_i = \frac{M_i}{L_i}$,$h_i^P = \frac{H_i^P}{L_i}$. I can rewrite the problem of this "large firm" in the intensive form. Note that h_i^P is not the human capital per capital in the production sector, but actually the ratio of the efficiency unit of skilled labor inputs to unskilled labor inputs; for simplicity, it is called the skilled-unskilled-ratio (SUR).

The per capita final output in a closed or an open economy is as follows:

$$y_c = A(m_c)^{\phi}(h_c^P)^{\alpha(1-\phi)}$$

$$y_o = A(Im_o)^{\phi}(h_o^P)^{\alpha(1-\phi)}$$

And the producer's problem is maximizing the per capita profit by choosing the optimal m_i and SUR h_i^P,

$$\max_{m_i, h_i^P} py_i - r_{mi}m_i - w_{hi}h_i^P - w_i$$

,where $i \in c, o$. If the maximum profit is smaller than 0 in country i, then the production sector shuts down there.

Take the first order conditions with respect to m and h^P, for both types of countries.

Producers in the closed economy would choose h_c^P and m_c, which solves :

$$\frac{\partial y_c}{\partial h_c^P} = \alpha_P(1-\phi)A(m_c)^{\phi}(h_c^P)^{\alpha_P(1-\phi)-1} = w_{hc} \tag{B.2}$$

$$\frac{\partial y_j}{\partial m_c} = \phi A(m_c)^{\phi-1}(h_c^P)^{\alpha_P(1-\phi)} = r_{mc} \tag{B.3}$$

Producers in a typical open economy would choose h_o^P and m_o, which solves :

$$\frac{\partial y}{\partial h_o^P} = \alpha_P(1-\phi)A(Im_o)^{\phi}(h_o^P)^{\alpha_P(1-\phi)-1} = w_{ho} \tag{B.4}$$

$$\frac{\partial y_j}{\partial m_o} = \phi A(Im_o)^{\phi-1}(h_o^P)^{\alpha_P(1-\phi)} = r_{mo} \tag{B.5}$$

Technology capital producers take as given the price of technology capital p_{Mi} , the price for the skilled efficiency unit w_{hi} and the average education level in country i $\bar{h}_i$, and they choose the optimal amount of production in each period that maximizes their profit.

The technology capital producer's problem:

$$\max_{H_i^T} p_{Mi} A_T(\bar{h})^{\psi} H_i^T - w_{hi} H_i^T$$

Take the first order condition:

The technology capital producer in a closed economy would choose:

$$\frac{\partial X_c}{\partial H_c} = p_{Mc} A_T (\bar{h}_c)^{\psi} = w_{hc} \tag{B.6}$$

The technology capital producer in a closed economy would choose:

$$\frac{\partial X_o}{\partial H_o} = p_{Mo} A_T (\bar{h}_o)^{\psi} = w_{ho} \tag{B.7}$$

Consistent condition:

Since the total rent for each unit of technology capital per period is R_{Mi} , and technology capital depreciates at rate δ_M , the value of each unit of technology capital equals$p_{Mi} = \frac{R_{Mi}}{\delta_M}$. for $i \in c, o$.

$$p_{Mc} = \frac{R_{Mc}}{\delta_M} = \frac{r_{mc}}{\delta_M} \tag{B.8}$$

$$p_{Mo} = \frac{R_{Mo}}{\delta_M} = \frac{I * r_{mo}}{\delta_M} \tag{B.9}$$

In addition, the average human capital in a country equals the sum of the total efficiency units of skilled labor used in both sectors divided by the total amount of skilled labor.

$$\bar{h}_i = \frac{H_i^P + H_i^T}{L} \tag{B.10}$$

Market clearing condition

The technology capital market is cleared: the technology capital being produced in each period equals the replacement demand for the depreciated technology capital.

$$A_T (\bar{h}_i)^{\psi} h_i^T = y_{Mi} = \delta_M m_i \tag{B.11}$$

$$c_i + \delta_h h_i = A(m_i)^{\phi}(h_i^P)^{\alpha(1-\phi)} \tag{B.12}$$

First Order Conditions:

Given that both types of country are in the steady state: from (B.1),

$$w_{hc}^* = w_{ho}^* = \frac{1+\rho}{A_e} = \frac{1+r^*}{A_e}$$

Rewrite equations (B.2)-(B.11) into the log form.

(B.2')

$$\ln(\alpha_P(1-\phi)A) + \phi \ln(m_c) + \alpha_P(1-\phi)\ln(h_c^P) = \ln(w_{hc}^*) + \ln(h_c^P)$$

(B.4')

$$\ln(\alpha_P(1-\phi)A) + \phi \ln(m_o) + \alpha_P(1-\phi)\ln(h_o^P) = \ln(w_{ho}^*) + \ln(h_o^P) - \phi \ln(I)$$

(B.3')

$$\ln(\phi A) + \phi \ln(m_c) + \alpha_P(1-\phi)\ln(h_c^P) = \ln(r_{mc}) + \ln(m_c)$$

(B.5')

$$\ln(\phi A) + \phi \ln(m_o) + \alpha_P(1-\phi)\ln(h_o^P) = \ln(r_{mo}) + \ln(m_o) - (\phi - 1)\ln(I)$$

(B.6')

$$\ln(p_{Mc}) = \ln(w^*_{hc}) - \ln(A_T) - \psi \ln(\bar{h}_c)$$

(B.7')

$$\ln(p_{Mo}) = \ln(w^*_{ho}) - \ln(A_T) - \psi \ln(\bar{h}_o)$$

(B.8')

$$\ln(p_{Mc}) = \ln(r_{mc}) - \ln(\delta_M)$$

(B.9')

$$\ln(p_{Mo}) = \ln(r_{mo}) + ln(I) - \ln(\delta_M)$$

(B.11')

$$\ln(A_T) + \psi \ln(\bar{h}_c) + \ln(h^T_c) - \ln(\delta_M) = \ln(m_c)$$

(B.11")

$$\ln(A_T) + \psi \ln(\bar{h}_o) + \ln(h^T_o) - \ln(\delta_M) = \ln(m_o)$$

Proof of the propositions

Proposition 1: When $\psi < \frac{(1-\phi)(1-\alpha_p)}{\phi}$, the domestic country has a lower steady-state technology capital stock (M), a lower steady-state education level (h), lower per capita output ($\frac{Y}{L}$), but a higher price for technology capital (P_M) than all the other foreign countries.

Proof:

Substituting (B.8) (B.9) into (B.6) (B.7) implies that

$$\ln(r^*) - \ln(A_T) - \psi \ln(\bar{h}_c) + \ln(\delta_M) = \ln(r_{mc}) \tag{B.13}$$

$$\ln(r^*) - \ln(A_T) - \psi \ln(\bar{h}_o) + \ln(\delta_M) - ln(I) = \ln(r_{mo}) \tag{B.14}$$

Substituting (B.3)(B.5) into (B.13) (B.14) implies that

$$\ln(\phi A) + \phi \ln(m_c) + \alpha_P(1-\phi)\ln(h_c^P) = \ln(w_{hc}) - \ln(A_T) + \ln(\delta_M) - \psi \ln(\bar{h}_c) + \ln(m_c) \tag{B.15}$$

$$\ln(\phi A) + \phi \ln(m_o) + \alpha_P(1-\phi)\ln(h_o^P) = \ln(w_{ho}) - \ln(A_T) + \ln(\delta_M) - \psi \ln(\bar{h}_o) + \ln(m_o) - \phi \ln(I) \tag{B.16}$$

Use (B.4) minus (B.2), (B.14) minus (B.13) and (B.16) minus (B.15)

We get (B.17) - (B.19)

$$\phi(\ln(m_o) - \ln(m_c)) + \alpha_P(1-\phi)(\ln(h_o^P) - \ln(h_c^P)) + \phi \ln(I) = \ln(h_o^P) - \ln(h_c^P) \tag{B.17}$$

$$\phi(\ln(m_o)-\ln(m_c))+\alpha_P(1-\phi)(\ln(h_o^P)-\ln(h_c^P)) = \ln(m_o)-\ln(m_c)-\phi\ln(I)-\psi(\ln(\bar{h}_o)-\ln(\bar{h}_c)) \tag{B.18}$$

$$\ln(m_o) - \ln(m_c) - \psi(\ln(\bar{h}_o) - \ln(\bar{h}_c)) = \ln(h_o^T) - \ln(h_c^T) \tag{B.19}$$

Substitute (B.19) into (B.18) ==>

$$\phi(\ln(m_o) - \ln(m_c)) + \alpha_P(1-\phi)(\ln(h_o^P) - \ln(h_c^P)) + \phi\ln(I) = \ln(h_o^T) - \ln(h_c^T) \tag{B.20}$$

Comparing (B.17) with (B.20), we notice that the LHS of (B.17) and (B.20) are exactly the same, which implies that

$$\ln(h_o^T) - \ln(h_c^T) = \ln(h_o^P) - \ln(h_c^P)$$

From (B.10), I know that

$$\ln(h_o^T) - \ln(h_c^T) = \ln(h_o^P) - \ln(h_c^P) = \ln(\bar{h}_o) - \ln(\bar{h}_c) \tag{B.21}$$

Substitute (B.21) into (B.19) ==>

$$\ln(m_o) - \ln(m_c) = (1+\psi)(\ln(h_o) - \ln(h_c)) \tag{B.22}$$

Then, substitute (B.22) this into (B.17), and we get

$$\phi\ln(I) = (1 - \alpha_P(1-\phi) - \phi(1+\psi))(\ln(h_o) - \ln(h_c)) \tag{B.23}$$

If $\psi < \frac{(1-\phi)(1-\alpha_p)}{\phi}$, then $1 - \alpha_P(1-\phi) - \phi(1+\psi) > 0 \implies \ln(h_o) - \ln(h_c)$ is increasing in I .

From (B.22,B.23), it is easy to show that $\ln(m_o) - \ln(m_c)$ is also increasing in I .

Since the closed economy has $I = 1$, while the open economy has $I > 1$, $\implies$

We know from (B.21) that: $h_o^P > h_c^P$, $h_o^T > h_c^T \implies \bar{h}_o > \bar{h}_c$, and, in addition, from (B.22): $Im_o > m_o > m_c$ in the production sector.

This result suggests that in the symmetric steady-state equilibrium, the open economy will have a higher equilibrium education level $\bar{h}$ and produce more technology capital than the closed economy.

Finally, regarding the equilibrium technology price, from (B.8) and (B.9), we know that $p_{Mo} < p_{Mc}$, which means that the return on technology capital is lower in the developed countries in equilibrium.

Proposition 2: After the developing country opens up to FDI, labor productivity in the final-production sector will converge; however, national income levels may not converge.

Proof:

Suppose that h_*^T, h_*^P,$\bar{h}_*$, m_*, r_{m*},w_{h*} are the values of model variables in those previously open economies in the new steady-state equilibrium, and h^T, h^P,$\bar{h}$, m, r_m, w_h the values of variables in those previously closed economies in the new steady state. In addition, we know that at the steady state,

$$w_h = w_{h*} = \rho + 1$$

Each country takes as given the other countries' choices, as well as the international prices for technology capital and final output.

Thus, the F.O.C for those previously open economies are summarized as follows:

The F.O.C for the final producers

$$\ln(\alpha_P(1-\phi)A) + \phi\ln(m + Im_*) + \alpha_P(1-\phi)\ln(h_*^P) = \ln(w_{h*}) + \ln(h_*^P) \tag{B.24}$$

$$\ln(\phi A) + \phi\ln(m + Im_*) + \alpha_P(1-\phi)\ln(h_*^P) = \ln(r_{m*}) + \ln(m + Im_*) \tag{B.25}$$

The F.O.C for the innovators

$$\ln(r_{m*}I + r_m) - \ln(\delta_M) \leq \ln(w_{h*}) - \ln(A_T) - \psi\ln(\bar{h}_*) \tag{B.26}$$

Market Clearing condition:

$$\ln(A_T) + \psi \ln(\bar{h}_*) + \ln(h_*^T) - \ln(\delta_M) = \ln(m_*) \tag{B.27}$$

$$\bar{h}_* = h_*^T + h_*^P \tag{B.28}$$

Similarly, the F.O.C for the previously closed economies are summarized by equations

$$\ln(\alpha_P(1-\phi)A) + \phi \ln(m + Im_*) + \alpha_P(1-\phi)\ln(h^P) = \ln(w_h) + \ln(h^P) \tag{B.29}$$

$$\ln(\phi A) + \phi \ln(m + Im_*) + \alpha_P(1-\phi)\ln(h^P) = \ln(r_{m*}) + \ln(m + Im_*) \tag{B.30}$$

The F.O.C for the innovators is (35), and it becomes equal when the domestic country produces in the innovation sector

$$\ln(r_{m*}I + r_m) - \ln(\delta_M) \leq \ln(r_h^*) - \ln(A_T) - \psi \ln(\bar{h}) \tag{B.31}$$

Again, the technology capital produced in each period equals to the replacement demand for the depreciated technology capital

$$\ln(A_T) + \psi \ln(\bar{h}) + \ln(h^T) - \ln(\delta_M) = \ln(m) \tag{B.32}$$

$$\bar{h} = h^T + h^P \tag{B.33}$$

It is easy to see that this system has three steady states.

The first steady state is when both (B.26) and (B.26) hold with equality; at this steady state, ten variables are solved from ten equations.

At this steady state: $h^P = h_*^P$, $h^T = h_*^T$, $\bar{h} = \bar{h}_*$,$m = m_*$,$r_m = r_{m*}$

When either (B.26) or (B.31) holds with inequality, there are two more steady states. If (B.31) holds with inequality, (B.26) must hold with equality. We can solve for the second steady state.

In this case, $m = h^T = 0$, and then (B.32) holds trivially

Then, we will have eight variables and eight equations to solve for the rest of the equilibrium results.

At this steady state, the domestic economy will specialize in the production sector, which is unskilled-labor-intensive.

In the above steady state, h^T, will be different across countries, however, notice that we will still have $h^P = h_*^P$ from (B.24) and (B.29), and the available technology capital in both developed and developing countries is Im_*. Thus, labor productivity and the total production output are equalized across countries.

If (B.26) holds with inequality, (B.31) must hold with equality. Then, I can solve the last steady state.

In this case, $m_* = h_*^T = 0$, and then (B.27) becomes trivial

Then, we will have eight variables and eight equations to solve for the rest of the equilibrium results.

At this steady state, the rest of the world will specialize in the production sector, and the domestic country will become the engine of the world that produces technology capital. However, again, we have $h^P = h_*^P$ from (B.24) and (B.29), and the available technology capital in both types of countries is m . The productivity and the total output in the production sector converge.

However, since the production sector converges, the returns to skilled and unskilled labor will converge across countries, and it is obvious that in cases 2 and 3, countries will have different stocks of human capital and, thus, the national income will not converge.

Proposition 3: After opening up, the domestic technology sector decreases in size over time.

Proof:

Two effects lead to the above result:

1. At the moment that a domestic country opens up to FDI, the return on technology capital will equate across countries immediately since $p_{Mo} < p_{Mc}$, and the production of technology capital is a constant return to scale. Thus, the new price for technology capital will equal the world price p_{Mo} immediately.

2. At the same time, productivity in the production sector rises dramatically due to the availability of foreign technology capital.

I will show that, after a country opens up, the skilled wage rate in the production sector is much higher than the skilled wage rate in the technology capital sector: let $(w^P_{hc})'$, $(w^T_{hc})'$ and p'_{Mc} refer to the return on skilled wages in the production sector, skilled wages in the technology sector and the value of technology capital, respectively.

When a country opens up, production factors are not ready to make any adjustment, and it is assumed that the stock of skilled and unskilled labor in both sectors stays the same as in the previous steady state.

From the production producer's problem, we know that

$$\ln(w^P_{hc})' = \ln(\alpha_P(1-\phi)A) + \phi\ln(m_c + I * m_o) + \alpha_P(1-\phi)\ln(h^P_c) - \ln(h^P_c) \quad \text{(B.34)}$$

From the innovator's problem, we know that

$$\ln(w^T_{hc})' = \ln(p_{Mo}) + \ln(A_T) + \psi\ln(\bar{h}_c) \quad \text{(B.35)}$$

From (B.2,B.34) we know that $\ln(w_{hc}^P)' > \ln(w_{hc})$

From (B.8,B.35) we know that $\ln(w_{hc}) > \ln(w_{hc}^T)'$

Thus, skilled labor will shift towards the production sector:

$==> (h_c^P)' > h_c^{*P}$ and $(h_c^T)' < h_c^{*T}$.

In addition, from the updating rule of technology capital (2.4), since $A_T(\bar{h}_i)^\psi (h_c^T)' < \delta_M m_c$, we know that $m' < m_c$.

The above result shows that the previously closed country would shrink its technology capital sector and become more specialized in the final production sector.